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The Role of 3D Printed Facsimiles in Fulfilling Museum Visitors' Desire to Touch

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Abstract

By nature, humans have a desire to touch the things they encounter in daily life. Museums are no exception to this desire, even though museum objects are rarely available for visitor handling. This thesis explores the question: "can accurate 3D printed facsimiles help fulfill the desire of visitors to touch museum objects?" For this project and case study, I selected, and 3D scanned a museum object, which was then recreated via 3D printing. The reproduction was then put on display alongside the original object, and a visitor study was conducted to see if interacting with the facsimile while seeing the original object satisfied the desire of the visitor to touch the object. From this study, I determined that the facsimile proved to be a satisfactory replacement for the original object in terms of touch – in this limited context. This research may be of use to museums and staff looking to meet visitor needs without compromising the institutional commitment to preservation, care, and stewardship of collections.

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Introduction

By nature, humans have a desire to touch the things they encounter in daily life. We are tactile beings, and touch can be used to give us information about the world surrounding us. In settings such as museums, however, touching objects is often discouraged or outright banned. In the past, museums have attempted to use facsimiles to provide visitors with a tactile learning experience, but often these facsimiles are merely similar objects, or reproductions that do not fully mimic the original. The emerging technologies of 3D scanning and printing, however, hold promise for allowing museums to easily and inexpensively create more accurate replicas of otherwise inaccessible objects. These reproductions, while useful, have yet to be truly explored in terms of whether visitors feel satisfied with their ability to simulate the experience of touching the original object. This thesis aims to understand the role that accurate 3D printed facsimiles can have on fulfilling the desire of visitors to touch museum objects.

Museum professionals understand why the ban on touching exists: objects might be too valuable, rare, or fragile to be touched except in very limited circumstances by someone trained in the profession. For visitors on the other hand, this ban is often not appreciated, and unauthorized touch remains a widespread problem in museums.[1] Because of this, more institutions are trying to incorporate hands-on experiences into their exhibits, whether it be interactives such as those typically seen in a children's museum or small tangible experiences throughout a gallery. While these opportunities can be good at helping engage visitors or demonstrate concepts, it does not have the same effect as being able to handle a museum artifact, which many visitors have a desire to do.

[1] Fiona Candlin, "Rehabilitating Unauthorised Touch *or* Why Museum Visitors Touch the Exhibits," *The Senses and Society* 12, no. 3 (2017): 256.

This project is divided into two sections. In the first, an object was selected from the collections of the Rochester Museum and Science Center (RMSC) and 3D scanned to create an accurate model of the object. This scan was then reworked using modeling software, until a satisfactory model was created. Following this process, the model was 3D printed using polylactic acid (PLA), a printable plastic, creating a tangible copy of the original object. For the second part of the project, the facsimile was placed back at the RMSC alongside the exhibited original, and visitors were invited to interact with the reproduction. A visitor study was conducted, and a survey was made available for visitors who wished to give feedback on their experience with the facsimile.

The goal of this project is to determine whether accurate 3D printed facsimiles of museum objects can help fulfill the desire of museum visitors to touch those objects. This could impact the museum field as it seeks to find new ways to engage audiences. 3D printing and scanning technologies introduce an easy and inexpensive means to create object reproductions, especially because they do not require any physical contact with a fragile object. Promoting the widespread use of such technologies could potentially provide visitors with the tactile experience they desire.

Literature Review

Since this thesis topic is multifaceted, associated research has been conducted in multiple areas: touch, facsimile, and 3D printing/3D printing process. Each of these areas is defined and discussed in the three sub-sections that follow. On the topic of touch, historical examples of touch being used in museums to interact with objects are explored, as well as motivations visitors might have for wanting to touch objects, and different types of touch. In facsimile, the history and use of facsimiles in museums around the world is discussed, as well as ways facsimiles are being used in museums and other cultural institutions to enhance the visitor experience. Finally, in 3D printing/3D printing process, different methods of 3D scanning and printing are analyzed, as are the applications 3D printed objects can have in a museum. Combined, this research provides better understanding of what has been accomplished so far in each area, as well as how each piece of the topic will come together to complete the project goal of seeing if accurate, 3D printed facsimiles can fulfill the desire of a visitor to touch museum objects.

Touch

Although the desire to touch museum objects has existed for as long as museums have, the concept of "hands-on" exhibits seems to be a fairly modern one, with almost all of the scholarship on this topic being created within the last 20 years. In historian Anna Maerker's article *Towards a Comparative History of Touch and Spaces of Display: The Body as Epistemic Object*, she notes that the creators of early museum models of the human body "responded to [the] persistence of touch by abandoning purely visual models of appropriation in favor of

displays which enabled physical contact with three-dimensional representations of the body."[2] For museum visitors in the late 18th century, touch was seen as an essential way to experience objects on display, and exhibits were specifically designed with the sense of touch in mind. In fact, the museum experience was seen not just as a visual one, but multi-sensorial, requiring visitors to use their senses of hearing, smell, touch, and sight in order to fully understand an object.[3] This fact is corroborated in *3D Printing for Cultural Heritage: Preservation, Accessibility, Research, and Education*, which notes that "the practice of touching, of being able to hold an object in your hands, had only been abandoned in the early nineteenth century," despite the fact that every museum visitor loves to touch the objects.[4]

Our natural desire is to touch objects we encounter in order to better understand them, but over time, the practice was discouraged due to our hands being seen as unclean, and prone to damaging the objects.[5] However, touch is sometimes necessary for a visitor to completely understand an object. For example, "buildings are ordinarily touched as well as seen, sculptures could be more fully appreciated if touched as well as seen, and even paintings may sometimes have enough three-dimensionality to repay touch experience."[6] Although it is an under-researched field, the concept of visitors having strong desires to touch museum objects has been explored to some degree by researchers.

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[2] Anna Maerker. "Towards a Comparative History of Touch and Spaces of Display: The Body as Epistemic Object." Edited by GESIS-Leibniz-Institut Für Sozialwissenschaften. Historical Social Research / Historische Sozialforschung 40, no. 1 (2015): Focus: 285. https://doi.org/10.12759/hsr.40.2015.1.284-300.
3 Maerker, "Towards a Comparative History of Touch and Spaces of Display, 286.
4 Moritz Neumüller et al., "3D Printing for Cultural Heritage: Preservation, Accessibility, Research and Education," in *3D Research Challenges in Cultural Heritage: A Roadmap in Digital Heritage Preservation*, ed. Marinos Ioannides and Ewald Quak, 121. Berlin: Springer Berlin Heidelberg, 2014. https://doi.org/10.1007/978-3-662-44630-0_9.
[5] Neumüller et al, "3D Printing for Cultural Heritage," 121.
[6] Neumüller et al, "3D Printing for Cultural Heritage," 120.

Art historian Fiona Candlin, who has published widely on the concept of touch in museum environments, notes in *The Dubious Inheritance of Touch: Art History and Museum Access* that touch is seen as a more "primitive" form of gathering information.[7] In her article, Candlin references research by Bernard Berenson in which he states that "as infants we understand depth and three dimensions through touch."[8] Touch, although seen as a more simple way of learning, is in fact very important in allowing us to make sense of the world. Touch as a form of learning might be one explanation for why visitors are so inclined to touch museum objects, but it is not the only one. In Candlin's book *Art, Museums and Touch*, she quotes from the diary of a wealthy visitor to the British Museum in the early 18th century. In the entry, the visitor discusses feeling connected to the original maker or user of objects while touching them, leaving Candlin to conclude that "handling the collections gave [the visitor] the sense that she was touching the hand of their previous owners, thereby creating a deep sense of intimacy and emotional involvement with the collections."[9] Besides learning from museum objects, visitors can use them to feel connected to the past, and our sense of touch helps to evoke those feelings more than sight ever could. This experience of evoking the past when holding an object of historical value might be difficult to replicate, if indeed it is a main motivator for why visitors want to touch museum objects.

Another potential reason for our desire to touch is to have a numinous experience, defined in *Numinous Experiences With Museum Objects* as a deeper and more meaningful connection with a museum object or objects; almost akin to a spiritual experience with an

[7] Fiona Candlin, "The Dubious Inheritance of Touch: Art History and Museum Access," *Journal of Visual Culture* 5, no. 2 (2006): 145, https://doi.org/10.1177/1470412906066906.
[8] Candlin, "The Dubious Inheritance of Touch," 141.
[9] Fiona Candlin, *Art, Museums and Touch*. Manchester: Manchester University Press, 2010, 71.

object.[10] In interviews conducted by museum studies scholar Kiersten F. Latham on this topic, she found that in every case of numinous experiences, the object, and specifically, the proximity to or ability to touch the object, allows the visitor to have a deeper connection with it.[11] Although this could be considered a part of touching the object in order to connect with its history, it is also important to note that a numinous experience goes much deeper than simply connecting with the past, and instead provides a completely different type of experience for the visitor. Numinous experiences have yet to be studied in more detail, but it is significant that the object itself, and the desire to hold it add value to this unique experience. Although several suggestions have been given as to why touch is such a desired part of a museum visit, these are only some of the many possible reasons that visitors desire to touch objects in museums.[12]

Despite the human desire to touch being widely acknowledged by museum professionals, little research has actually been done into the topic, and even fewer publications give multiple potential reasons for visitors' desire to engage physically with a museum object. Throughout Fiona Candlin's article "Rehabilitating the Unauthorised Touch *or* Why Museum Visitors Touch the Objects," she attempts to describe and assign names to the motivations visitors have for touching objects, by exploring the unauthorized touching visitors do. Moreover, Candlin cites a desire to test the authenticity of the object, a desire to learn, a desire to connect with the past, and a desire to have fun or make a joke as some of the main reasons why visitors will touch objects, even if they are not allowed to.[13] She also notes that many visitors feel almost as if they *have* to touch the object, and that most of the time, the touching of objects is not meant to be destructive,

[10] Kiersten F. Latham, "Numinous Experiences With Museum Objects," *Visitor Studies* 16, no. 1 (2013): 3–20, https://doi.org/10.1080/10645578.2013.767728.
[11] Latham, "Numinous Experiences With Museum Objects," 9.
[12] Other reasons suggested by Latham include wanting to feel the "aura" that an object has, to feel connected to other people, and to bring the object to life.
[13] Candlin, "Rehabilitating Unauthorised Touch," 251–66.

but instead meant to connect visitors with "the people and places of the past."[14] Candlin's analysis of why people touch is just one framing for this concept.

In *Towards a Comparative History of Touch and Spaces of Display: The Body as Epistemic Object,* Maerker proposes another list of motivations for touching objects: sensual touch (for enjoyment), skeptical touch (to verify), connoisseurial touch (to judge quality), learning touch (to increase knowledge), controlling touch (to claim the object), and the healing touch (for religious or curative purposes).[15] Like Candlin, Maerker also notes that touching objects does not necessarily indicate a "[sign] of disobedience or lack of discipline."[16] These two lists share many of the same motivations for touch, but there are also important differences. Candlin's list is not as extensive as Maerker's, and misses the ideas of connoisseurial touch, controlling touch, and healing touch; although she suggests connecting with the past as a motivation, which Maerker does not. Overall, however, these two examinations make it clear that there is not a single motivator for why visitors touch or have a desire to touch museum objects. Motivation can be multifaceted, encompassing one or more of the reasons suggested by Candlin and Maerker, or could be fueled by something else entirely. The concept of touch in this context is a complicated and under-explored topic, but the one thing that is clear is that almost everyone has a desire to touch the objects they encounter in museums.

[14] Candlin, "Rehabilitating Unauthorised Touch," 263.
[15] Maerker, "Towards a Comparative History of Touch and Spaces of Display," 294-295.
[16] Maerker, "Towards a Comparative History of Touch and Spaces of Display,"294.

Facsimile

Similar to touch, the use of facsimiles in museums is not a new concept but is a subject that has received little study.[17] The research that does exist, however, suggests that facsimiles can serve as a powerful supplement to the object they are imitating, allowing visitors to interact with museum objects in a way they never could with the original. Indeed, this was the motivation behind the creation of one of the earliest and best-known facsimiles: a plaster cast of Trajan's Column that stands in the Cast Courts at the Victoria and Albert Museum. The cast exists today as a relic of the practice of casting, a popular procedure from the Renaissance through the 19th century that would allow for an accurate three-dimensional copy of an object to be made.[18] These casts were especially important before the advent of photography and grew in popularity during the mid-19th century when world's fairs and other spectacles promoted bringing grand objects to everyday people. Additionally, they were used to help train artists, allow people who were unable to travel to the object to view it, and for up-close study of the object.[19]

In the case of the cast of Trajan's Column, the facsimile was made specifically for the Victoria and Albert Museum, where starting in 1873, "it provided the opportunity for students (and others not able to travel to Rome) to see this iconic monument of the classical world."[20] Today, however, due to the large pedestals that the column sits on, and its display in two pieces since it is too tall for the gallery, it is impossible to study the column in detail.[21] Despite these limitations, the case of Trajan's Column suggests the importance of facsimiles, and especially

[17] Educational teaching collections and casts can also serve this purpose, however, since they are not the focus of this paper, their role in museums will not be addressed.
[18] Jon Coulston, "The Study of Trajan's Column | Trajan's Column," Trajan's Column. Accessed October 14, 2018, https://arts.st-andrews.ac.uk/trajans-column/the-project/the-study-of-trajans-column/.
[19] Coulston, "The Study of Trajan's Column."
[20] Victoria and Albert Museum. "Trajan's Column - Victoria and Albert Museum." Last modified 2016. Accessed October 4, 2018. http://www.vam.ac.uk/content/articles/t/trajans-column/.
[21] Coulston, "The Study of Trajan's Column."

early facsimiles: they can be used to teach, show more detail than a photograph or other copy, and serve as a way to make an otherwise inaccessible object accessible to visitors.

The importance of facsimiles has been explored in other ways as well. In a 2016 *New Yorker* article titled "The Factory of Fakes," author Daniel Zalewski explores Factum Art, a Madrid-based company that specializes in making incredibly accurate reproductions of paintings, sculptures, and even entire rooms.[22] Factum Arts reproductions are created by intensely 3D scanning the original object if available, or by studying other works by the same artist if the desired work is not available.[23] These high-quality scans are then either 3D printed or milled, creating an amazingly accurate reproduction of the original object.[24] As Zalewski describes in his article, these facsimiles can have a wide variety of uses. Some, such as a full-scale reproduction of King Tutankhamun's tomb, allow for the original "object" to be protected, while still providing access to the site, or easier access depending on where the original object is.[25] Reproductions can also allow for up-close study by researchers of the object, to preserve a moment in the object's lifetime, or to replace the original if it has been damaged or is otherwise unavailable.[26] Especially for an accurate facsimile, such as the ones being created by Factum Arte, the opportunity to interact with a near-perfect replica of an object can be an invaluable experience to many groups of people, further stressing the importance of facsimiles in research, access, and preservation.

Finally, facsimiles can be used to add value to the object they are meant to be imitating. In the study *Dead Ringer? Visitor's Understanding of Taxidermy as Authentic and Educational*

[22] Daniel Zalewski. "The Factory of Fakes." *New Yorker* November 28, 2016, 69-79. https://www.newyorker.com/magazine/2016/11/28/the-factory-of-fakes.
[23] Zalewski, "The Factory of Fakes," 69-79.
[24] Zalewski, "The Factory of Fakes," 72.
[25] Zalewski, "The Factory of Fakes," 69-79.
[26] Zalewski, "The Factory of Fakes," 69.79.

Museum Exhibits, research was conducted to see whether being able to physically interact with a taxidermied animal, or with a toy version of that animal, would make visitors value the "authentic" object more. For the study, visitors were shown a taxidermied rabbit, and were allowed to either look at it, touch it, or touch a toy rabbit that resembled the real one.[27] The study found that although most visitors said that the taxidermied rabbit was worthy of belonging in a museum, and that it helped them learn about rabbits, the percentage of visitors who gave these answers increased significantly when allowed to touch the object, and went up even further when given the toy rabbit to touch, and the actual rabbit to look at.[28] Thus, the authors of this study concluded that "these findings supported the hypothesis that the toy condition would highlight the authentic properties of the taxidermied rabbit."[29] The toy rabbit was obviously not a perfect replica of the taxidermied rabbit, but being able to hold a facsimile of the object undoubtedly gave value to the original object for museum visitors. Based on these findings, it is not unreasonable to assume that in most cases, visitors find greater value in an object if they are able to interact with it, or even if they interact with a facsimile of it. The literature that exists on facsimiles in museums all seem to suggest that not only are facsimiles a well-known method of learning, they can add value to a museum experience in a multitude of ways.

[27] Louise Bunce, "Dead Ringer? Visitors' Understanding of Taxidermy as Authentic and Educational Museum Exhibits," *Visitor Studies* 19, no. 2 (2016): 182, https://doi.org/10.1080/10645578.2016.1220189.
[28] Bunce, "Dead Ringer?," 183.
[29] Bunce, "Dead Ringer?," 186.

3D Printing/3D Printing Process

Unlike many other museum technologies, 3D printing has not been utilized for very long. The actual concept for and ability to 3D print materials is older, having initially been developed in the 1980s, but 3D printing has only become affordable and available for widespread use within the last decade.[30] Despite its newness, research has been conducted in the field to see what methods of scanning and creating 3D models are most effective for different types of objects and situations. In the article *Creation and Preservation of Digital Cultural Heritage*, a number of different methods and types of 3D scanners are compared to see which type of scanner produces the best results, and for what types of objects. Laser scanning, 3D modelling, digital sculpting, and photogrammetry are compared in this article, and each method results in different advantages and disadvantages.[31]

Laser scanning involves projecting a light source onto an object, which is then detected by an optical detector. The placement of the line produced by this light source allows the system to extract the shape of the object in the form of a point cloud, which can then be manipulated post-scan.[32] This method, although it can require work post-scanning, seemed the most likely to be useful for my project, since I had access to laser scanners and the software needed to manipulate the scans through my school. Laser scanners can also be handheld, and some of the more advanced ones can detect surface texture, making them suitable to scan and print an accurate 3D facsimile.[33] It should be noted, however, that although this article provides

[30] Dana Goldberg. "History of 3D Printing: It's Older Than You Think [Updated]." *Redshift EN* (blog), April 13, 2018, https://www.autodesk.com/redshift/history-of-3d-printing/.
[31] Randu Comes, Zsolt Buna, and Ionut Badiu, "Creation and Preservation of Digital Cultural Heritage." *Journal of Ancient History and Archeology* 1, no. 2 (August 2014): 51–55.
[32] Comes, Buna, and Badiu, "Creation and Preservation of Digital Cultural Heritage," 51.
[33] Comes, Buna, and Badiu, "Creation and Preservation of Digital Cultural Heritage," 51.

interesting and helpful information about the laser scanning process, it was also written in 2014, and the technology might have changed since then.

From Scan to Print: 3D Printing as a Means for Replication also discusses the post-scan work required to create an accurate 3D model of an object. This article specifically mentions how objects that have moving parts or holes, are shiny or reflective, or are too high contrast can be difficult to scan well.[34] These possible complications will be important to consider when selecting an object to scan. The article goes on to discuss different methods of scanning, as well as the post-scan process of printing and converting. According to the article, an "average of 8 to 16 scans must be combined in order to create a complete 3D object," and care must be taken to ensure that the scan does not have extra data, missing surfaces, or other flaws that would affect the final model.[35] Models that contain a lot of points in the mesh cloud will end up being more uneven than models with few mesh points, which will also be important to consider depending on the texture of my selected object.[36] Both of these articles provide helpful information about the 3D scanning and modelling process, and give insight into what steps should be taken to create an accurate 3D facsimile of an object.

As 3D scanning and printing can be used to create accurate reproductions of objects, these technologies have varied applications in museums and other cultural heritage institutions. One purpose can be to learn more about objects without damaging them, as detailed in *Re-Engineering Watt: A Case Study and Best Practice Recommendations for 3D Color Laser Scans and 3D Printing in Museum Artefact Documentation.* This article, published in 2012, discusses

[34] Susanne Klein et al., "From Scan to Print: 3D Printing as a Means for Replication," Hewlett-Packard Development Company, 2014, 6. https://www.semanticscholar.org/paper/From-Scan-to-Print%3A-3D-Printing-as-a-Means-for-Klein-Avery/cb598dac18ffdb83252ad736dc632679054052ce#paper-header
[35] Klein et al, "From Scan to Print," 2.
[36] Klein et al, "From Scan to Print," 2.

using 3D scanning and printing in order to produce a "positive" 3D model of a "negative" plaster-cast form owned by scientist James Watt, a Scottish engineer whose improvements upon the steam engine allowed for the Industrial Revolution to occur.[37] The cast, which was designed to be filled with plaster in order to create a sculpture, depicted a bust of a man, but it was impossible to tell who the man was without casting the model; a process that would irreparably damage the cast.[38] Instead of creating this irreversible damage, museum staff were able to 3D scan each piece of the mold without touching it, make the scans positive, and piece them together to complete the bust.[39] In doing this, the museum discovered the bust was a never-before seen sculpture of James Watt, and the final 3D print was able to be placed on display along with the cast it came from.[40] In this case, 3D scanning and printing was used to learn more about a museum's collections, and to do so in a way that would not damage the fragile object.

Another use of 3D modelling and printing is to create objects that can be handled and used for educational purposes, as well as to increase access to the materials. In Katherine Curran's thesis *The Process of Creating Accurate Reproductions of Fragile Objects: Fabricating 3D Facsimiles with Limited Resources*, the process of 3D scanning and printing an accurate facsimile of a papier-mâché book held by the Melbert B. Cary Graphic Arts Collection is detailed. The book, which has elaborate papier-mâché designs on the front and back covers is incredibly fragile, and unable to be handled without great care.[41] The project consisted of carefully 3D scanning the book, then manipulating the digital model to be as accurate as

[37] Mona Hess and Stuart Robson, "Re-Engineering Watt: A Case Study and Best Practice Recommendations for 3D Colour Laser Scans and 3D Printing in Museum Artefact Documentation," Proceedings paper, Lasers in the Conservation of Artworks IX, 2013: 156. http://www.lacona9.org/publication.php
[38] Hess and Robson, "Re-Engineering Watt," 157.
[39] Hess and Robson, "Re-Engineering Watt," 157-158.
[40] Hess and Robson, "Re-Engineering Watt," 159-160.
[41] Katherine Curran, "The Process of Creating Accurate Reproductions of Fragile Objects: Fabricating 3D Facsimiles with Limited Resources," Undergraduate Thesis, Rochester Institute of Technology, May 1, 2017: 19. https://scholarworks.rit.edu/theses/9597

possible, and eventually 3D printing the facsimile. At the end of the project, "the Cary Collection receive[d] a digitally-rendered surrogate which acts as a physical educational object… [and] the digital scans of the book cover for education and access use online."[42] The end result of this project thus served a twofold purpose: to serve as an educational resource onsite, and to function as a digital resource that provides easier access to this item. Both of these uses are important museum functions and can affect a patron's experience when visiting the Cary Collection. It is clear therefore, that 3D scanning and printing in the museum field can serve a wide range of uses and can create a positive impact for the institution whose items are being recreated digitally. Additionally, this research suggests that 3D printed facsimiles could be of interest to visitors and could possibly provide a tactile experience they would otherwise be unable to have.

[42] Curran, "The Process of Creating Accurate Reproductions of Fragile Objects," 21.

Research Methodologies

Building upon preliminary research about touch, facsimile, and 3D printing/3D printing process, this thesis involves a second element, a project component. For this, I selected, and 3D scanned a museum object, which I recreated via 3D printing. The reproduction was put on display alongside the original object over a limited period of time, during which I conducted a visitor study. From this study, I determined whether the facsimile proved to be a satisfactory replacement for the original object in terms of touch.

Selecting an Object

My first step in completing this project was to find a museum object that I would be able to scan, 3D print, and put on display for visitors to handle. From the research conducted for my literature review on 3D printing, I understood some physical criteria that this object needed to have, or not to have, in order to scan and print successfully with the equipment I had access to. For instance, I did not want anything with holes, moving parts, or that was too reflective. These features tend to become distorted during the scanning process and can be difficult to resolve later. The amount of detail an object had was also something I wanted to consider during selection. An object with a lot of detail might be more interesting for a visitor to handle, but it would also be difficult for the scanner to recognize and process. Therefore, I was looking for something that did not have intricate details such as carvings. I also considered material when selecting my object, given that some materials would be poorly replicated through reproductive means. I felt that materials that were smoother, such as china, glass, or metal would not translate

well into a 3D print, and thus objects made of these materials would not make good candidates for this project.

Additionally, I wanted my object to be something that people would be interested in touching. Because my study relied on people handling and interacting with the 3D reproduction, I needed my original object to be an item that people would naturally wish to touch. Using an object that served a specific function and was slightly familiar to visitors could reasonably ensure that people would want to handle the reproduction. I also prioritized finding an object that did not have small parts and was not fragile, so it could not be easily damaged while available for visitor interaction.

In addition to selecting an object, I also had to select a location at which to conduct my study. My original hope was to choose an object from the collection at the Rochester Institute of Technology (RIT) Archives, and to put the object and reproduction on display somewhere on RIT's campus. However, this would have limited the age range of the study participants and would have been difficult to do in a college setting as opposed to a museum setting. Instead, I decided to shift my project to the Rochester Museum and Science Center (RMSC), a local science and technology museum that has extensive history collections despite its name.[43]

I believed that the RMSC would be an appropriate venue for my project for several reasons. While the museum is aimed primarily at a younger audience, people of all ages visit as well. This wide age range would allow me to collect a variety of participant responses, whereas other museums in Rochester tended to serve only a particular age demographic or audience. In addition to catering to a broad audience, the RMSC is very hands-on, with opportunities for

[43] For further information on the Rochester Museum and Science Center, please refer to their website: https://rmsc.org/

interaction spread throughout the museum. Interaction is crucial for this project, so I felt that hosting it at an institution where interaction is expected would be beneficial when gathering data.

With these factors in mind, I made an appointment to speak with Elizabeth Pietrzykowski, the Registrar of the RMSC. After explaining my project and the type of object I was looking for, we decided to tour the galleries along with Dr. Calvin Uzelmeier, Director of Featured Content, Exhibition Support & Special Projects at the RMSC. Pietrzykowski believed it would be easier to select an object already on display in the museum so that we would not have to worry about setting up an exhibition for the object, and we first decided to look at the RMSC's two exhibits devoted to Native American artifacts: *At the Western Door,* and *Native Peoples of the Americas*.

While looking in these galleries, Uzelmeier noticed a wooden snow visor on display in the section about Arctic Natives (see Figures 1 and 2). The visor met nearly all my requirements: it had a flat, smooth surface, no moving parts, and was made of a material that would most likely be recreated well as a 3D print. Most importantly, the visor was an object designed for use, meaning that visitors would be more likely to have a desire to handle the reproduction if given the opportunity. The native exhibits at the RMSC have little to no interactivity involved, so this opportunity would stand out in the gallery. My only concern with the visor was that the slit at the front, as well as the open back, would prove difficult to scan. However, we decided that because these areas were so large, any defects during scanning could be easily removed during processing. After discussing this item with Pietrzykowski and Uzelmeier, we settled on the snow visor as my object.[44]

[44] While discussing my potential use of the snow visor, I inquired about using an object that was native-made, because I did not want to be disrespectful to any Native cultures by reproducing it. Elizabeth Pietrzykowski

The snow visor I selected as my object was created by Native Peoples living in the Arctic and was used to minimize glare and limit the amount of light that entered a user's eyes, similar to modern-day sunglasses.[45] The goal of the visor, also known as snow goggles, was to block as much light as possible and constrict the user's field of vision to prevent snow blindness when on snowy terrain. The pair of goggles at the RMSC is made of wood, but similar goggles have been found that are made of walrus ivory, bone, or driftwood.[46] The goggles would have been carved to fit the face of the wearer, and sometimes soot would be put inside to further darken the field of view.[47]

Scanning the Visor

After selecting my object, the next step was to 3D scan it. For this stage of the process, I enlisted the help of Jade Myers, an adjunct faculty member in the Kate Gleason College of Engineering at RIT who specializes in 3D technologies for accessibility. After sharing my images of the visor, Professor Myers and I created a crude version of the visor out of cardboard so that we could simulate scanning with the actual museum object (see Figure 3). For the purposes of this project, Professor Myers allowed me to use the 3D scanner she uses for her work, a Structure Sensor. This is a small device that attaches to an iPad and allows for easy

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explained to me that the RMSC has been very diligent in their compliance to NAGPRA, and that the museum has been given explicit ownership and usage rights to all the Native objects currently held by them. Additionally, previous work at the museum has led to a wood reproduction of this specific item, so reproducing with 3D printing posed no ethical concerns.

[45] "Inuit Snow Goggles," Vancouver Maritime Museum, March 14, 2007, https://web.archive.org/web/20070314111555/http://www.vancouvermaritimemuseum.com/modules/vmmuseum/treasures/?artifactid=77.

[46] "Inuit Snow Goggles."

[47] Smithsonian Institution, "Snow Goggles," Alaska Native Collections, accessed February 19, 2019, https://alaska.si.edu/record.asp?id=550.

capture of objects, although it struggles to pick up finer details. Luckily, the visor was smooth and did not have any fine details and this scanner worked perfectly for our needs.

To operate this scanner, the user must first define the area of the object using a virtual viewing cube that surrounds the object as it appears on the iPad screen. Once the cube is adjusted to include the entire object, the user can begin scanning. After some trial and error, we decided the best way to scan the entire object was to move ourselves 360˚ around it, while keeping the object in view at all times. As it scans, a white model of the object appears on the screen, showing you what the scan will look like when complete. Once finished, the user can then examine the scan to determine whether another one needs to be taken. After practicing with our cardboard model, Professor Myers and I made plans to go to the RMSC and scan the real object.

Our first challenge at the RMSC was finding a suitable way to support the visor so it could be scanned from all angles without our support interfering with the scan. After experimenting with different stands, we settled on using a piece of wood with two thin arms extending from a base, and each arm ending in a point. The points were placed through the slit of the visor, allowing it to rest while only being supported by these two small points (sees Figures 4 and 5). Once we had a stable stand for the visor to rest on, Professor Myers and I completed the scanning process (see Figure 6) and took two scans to ensure we had what we needed. After scanning, we used calipers to measure each portion of the visor and recorded the measurements (see Figure 7). These would be needed to process the scan appropriately.

Processing the Scan

With the scanning completed, it was time to move onto the next stage of processing the scans. After exporting the scans, it was clear that significant digital work needed to be done to make them look like the original object. Professor Myers had anticipated the scanner would struggle with the slit on the front of the visor, so we had planned on slicing that part out of the model once we began working with it. Unexpectedly, the scanner also struggled to capture the open back of the visor and filled it in with a large piece of excess material (see Figure 8). Before anything else could be done with this scan, this excess material at the back of the visor needed to be removed.

I first tried to work with the scan using the program Meshmixer, which allows the user to manipulate 3D scanned objects as if they were clay. After struggling with getting the program to do what I needed, however, I turned instead to using Autodesk Fusion 360, a CAD program that allows you to manipulate objects in a 3D environment. I had never used this program before and it has a steep learning curve, so I was able to get assistance from John Lyons, an Industrial Design student at RIT who works with Professor Myers and has extensive experience with Fusion 360. With John's help, I was able to cut off the extra material, scale the visor to its correct size, and remove the material for the nose hole indentation and the slit at the front (see Figure 9).

With this done, we then needed to thicken the scan, since up until this point it had been a mesh model without a thickness. Normally this can be done in Fusion, but this mesh model had too many planes, or surfaces that make up the figure. This meant it would not thicken, since it caused the planes to overlap each other. After trying several ways to fix this in Fusion, Professor Myers recommended we bring the model back into Meshmixer and use the "offset" tool to give it

a thickness. This worked perfectly, and the model was brought back into Fusion to finish cleaning it up.

However, after moving the model back to Fusion, we were met with a new problem. The mesh model needed to be converted into a solid, so John suggested I download a third program, MeshLab. Using that we were able to convert the mesh model into a solid object. For the rest of the processing, we were able to remain in Fusion, and work with the tools available in that program.

At this point, I had to make decisions regarding the accuracy of my reproduced visor. After the initial edits, the scan was not symmetrical and had several bumps on one half that were not present on the original object. The original object was not perfectly symmetrical and was several millimeters longer on one side than on the other. I discussed the accuracy of the model with several peers and faculty members and we decided it would be best to remove these defects. John suggested I cut my model in half, and then mirror it so that it would be perfectly symmetrical. Although this means that it is not a perfect reproduction of the original visor, we believed that the differences would be small enough that it would not impact a visitor's perception of the facsimile, and would overall, make the model stronger.

The final step was to put a hole in each side of the model, so that a cord or strap could be later installed like on the original visor. With this done, the processed scan was declared complete (see Figure 10), and we moved on to making a test print of the visor.

Creating the Facsimile

After the finished model was created, I returned to Professor Myers to do a test print of it. After showing me how the 3D printer works and what settings to use with it, she helped me set up my model correctly using a software called Cura (see Figure 11). This software, which is made by Ultimaker, works with the Ulitmaker-brand printers to help users prepare, or "slice" their scans for 3D-printing. For this step, we decided to print using polylactic acid (PLA), a common material used for 3D printing that is made from renewable resources.[48]

While preparing the model to print, we chose to add on a brim and supports. Because the visor was not perfectly flat on any side, it would require support materials to hold up parts of the object that were not touching the build plate while printing. By adding a brim (an extra piece of material on the surface touching the build plate) and supports that sit on the outside of the print, we were able to make sure the model printed correctly (see Figure 12). Because these pieces are excess, they are printed to be later removed, which can be done by breaking them off by hand or with pliers, by chiseling them off, or by using sandpaper to remove any excess. For my models, all three methods were used to remove the brim and supports from the print.

Once the scan was ready and loaded onto an SD card, we began trying to print it. Our first few attempts went poorly, as the print was having trouble sticking to the build plate of the printer. After switching machines, however, we were able to successfully begin the print. This first test print, which took approximately 10 hours to print, and used 115 grams of PLA, had some serious flaws upon first viewing it (see Figures 13 and 14). The most obvious flaw was that although I had scaled my model in Fusion to what I believed was the correct size, the print was

[48] Tony Rogers, "Everything You Need To Know About Polylactic Acid (PLA)," accessed January 31, 2019, https://www.creativemechanisms.com/blog/learn-about-polylactic-acid-pla-prototypes.

significantly larger than it was meant to be. Thankfully, this was easy to fix. However, there was another obvious flaw in the shape of the nose hole. Because the scan had filled in the open back of the visor, I had to create the shape of the nose hole myself. The shape seemed fine in Fusion, but upon printing, it was clear that the hole was significantly wider than a person's nose. This meant I would have to fill in the sides of the hole in Fusion so that I could create a more accurate nose hole. In terms of the overall shape, however, I was satisfied with how the visor turned out, especially considering that it was a test print.

After assessing the print, I went back into Fusion to begin fixing the errors. I first began by resizing the model, which I discovered was roughly 25% too large. After this simple edit, I moved on to fixing the shape of the nose hole by filling in additional material. Due to the way the model was constructed, I was not able to simply pull the sides in to create this material. Instead, I drew two plane shapes that mimicked the correct shape of the nose hole, gave them a thickness, and joined them with the larger visor model (see Figure 15).

The second test print took roughly 5.5 hours to print and used about 50 grams of filament. Once the print finished, it was immediately clear that it was a much stronger model. The print was significantly smaller than the original test print and was much closer in size to a person's face. Additionally, the reshaped nose hole allowed the visor to better fit against a user's face, further improving the quality of this print (see Figures 16 and 17). I was fairly confident in this model serving as an accurate reproduction of the original, but I still decided to take the same measurements on it as I had on the original to ensure that it was the correct size. While doing this, I discovered it was several millimeters smaller than the original object, or roughly 3% too small.

Although this error most likely would have gone unnoticed by a visitor, I decided to reprint the visor for a third time using brown filament instead of the clear/blue filament I had used for the first two prints. This would allow the visor to block out light the way the original object was intended to and make the reproduction more closely resemble it. Since I was reprinting my model anyway, I also scaled up this print slightly so that it would better match the size of the real visor.

The third print took approximately 9.25 hours to print and used 92 grams of filament. It was by far the most accurate model that had been created, and I felt confident that it could be used for my visitor study. The finished print, however, did need to be worked with slightly before it could be used. First, the brim, which had kept the visor stable during printing, needed to be removed (see Figure 18). This was completed by snapping it off with pliers and by hand, and then sanding and chiseling the excess material off (see Figure 19). Other parts of the visor, such as the nose hole and the parts that rested against the face also needed to be sanded. This sanding process removed defects that were on the model and smoothed out rough edges that would be uncomfortable when pressed against a visitor's face (see Figure 20). The visor was sanded with 150, 220, and 2000 grit sandpaper until the surface of the problem areas were smooth and even. This sanding phase took approximately 30 minutes to complete.

Unfortunately, sanding the visor to this degree left it discolored in some areas, which looked odd when compared to the rest of it (see Figure 21). To remedy this, I painted the surface of the visor using brown acrylic paint, which I airbrushed on (See Figure 22). I painted roughly three coats of paint on each side of the visor, including the inside, which left the entire model a fairly even brown color (see Figure 23). Finally, a complete, accurate version of the visor was ready for user testing.

Putting the Facsimile on Display

While preparing for my visitor study, I arranged to spend three days at the RMSC doing observations. I was asked by Elizabeth Pietrzykowski, the Registrar of the RMSC, to remain at the museum while the visor was on display, so that I could ensure the safety of the visor as well as facilitate if need be. The scheduled days were over February break for K-12 schools. I hoped that since these times were during a school break, the museum would be busier than usual, and I would be able to collect sufficient data.

In order to create a satisfactory visitor setup, I brought a number of items with me to help facilitate the visitor's experience. In addition to my reproduced visor, I brought an iPad and stand so that visitors could fill out a survey about their experience with the object (see Figure 24). I also provided slips of paper with a link to the survey (see Figure 25), hand sanitizer and baby wipes to sanitize the visor between uses, and a trashcan to dispose of the wipes.[49] Label copy about the visor was written by me and edited and printed by RMSC staff to provide context about the visor for visitors (see Figure 26). Furthermore, I created signs advertising the experience, which the RMSC had printed for me, and placed on easels around the museum (see Figure 27). The museum also provided a pedestal for all the items, which I placed in front of the case with the original visor on it (see Figure 29). With the setup complete, I sat roughly ten feet away from the objects in order to keep an eye on the visor and iPad, and to track how many people engaged with the visor.

[49] As part of this thesis project, I applied for and received funding from RIT's College of Liberal Arts Student Research Fund. The money I received was used to purchase supplies for user testing, as well as pay for the filament used in printing the visor. It was also used to purchase the Amazon gift cards for the randomly-selected survey respondents.

Visitor Study

In addition to my on-site observations, I wished to obtain visitor feedback on their experience with the visor. Therefore, I created an online survey using Google Forms that visitors could complete regarding their experience with the facsimile visor (See Appendix A, Figure 1 for a full copy of the survey). The use of Google Forms enabled the survey to be completed onsite or offsite after visitors experienced the surrogate visor. The questions were divided into three categories: 1) information from the visitor about their experience with the visor; 2) demographic information; and 3) contact information.

The first series of questions dealt with the visitors' interactions with the facsimile. Because my main research question involved determining if the facsimile helped fulfill a visitor's desire to touch the original object, most of the questions centered on this topic. I began by asking visitors about what type of objects they like to touch in museums, allowing them to choose from a list of options. The second question asked visitors to rate on a scale of 1-5 (with 1 being "absolutely no desire" and 5 being "very strong desire") if they had a desire to touch the real snow visor, or another similar object prior to the experience they just had. These first two questions were meant to determine if visitors did actually have a desire to touch museum objects. The third question asked visitors to rank on a scale of 1-5 (with 1 being "absolutely did not fulfill" and 5 being "completely fulfilled") if touching the reproduction fulfilled this desire, with an option to add a longer explanation if so desired. The fourth question asked visitors if the texture of the replica matched their expectations, with the option to select "Yes," "No," or "Not sure." This question was meant to determine if the 3D printing process created a satisfactory reproduction of the object. Finally, I asked visitors to rate on a scale of 1-5 (with 1 being

"absolutely did not enjoy" and 5 being "very much enjoyed") if they enjoyed touching the reproduction, with an option to leave a longer explanation if so desired.

All these questions were intentionally written to not be leading and allow the visitor to give honest feedback about their experience. The questions were designed to be answerable by visitors of all ages, and options were given for further explanation if the visitor had feedback they wished to give that was not included in a question.

In the demographic section, I asked visitors to answer some basic, unidentifiable information about themselves. I first asked visitors to select their age from a list of ranges, and their highest level of education from a list of ranges. I wanted to know the age range and education level of visitors so that I could understand whether or not a child or adult was taking the survey, and to understand what prior knowledge, if any, they were bringing to the experience. I also asked them to select from a list of options who they visited the museum with on this visit, so that I could have a sense of the age demographics of the other members of their party. I also asked visitors to answer how many people were in their group, so I could see whether the survey was potentially being completed for multiple people at the same time.

In the final section, I asked visitors to leave their name and email address, with the option to not do so if desired. The purpose of this section was to collect contact information to later reward visitors who answered the survey with a prize.

When discussing this project with my advisors, as well as other faculty members and peers within my program, there was a repeated concern about getting enough data to draw conclusions. The gallery in which my observations were taking place is out of the way and tends to not receive as much traffic as the more hands-on exhibits. We hoped that having signs placed

throughout the museum would draw visitors, but in case it did not, we discussed and ultimately decided to offer the chance to win a monetary reward to visitors who completed the survey. Visitors who gave their contact information in the third section of the survey would be entered into a drawing to win a $25 Amazon gift card. One out of every fifty visitors would win a card, with the winners being chosen randomly, and the contact information being separated from the visitors' answers prior to selection so there would be no bias when choosing winners. Once winners were chosen and contacted, the contact information of all visitors would be discarded. We believed that this would increase survey responses, while not allowing any biases to influence who received the rewards for answering.

Findings

Preliminary Study

Prior to doing my user testing at the RMSC, I was able to do some preliminary testing with college students at Rochester Institute of Technology (RIT). Students enrolled in MUSE 360, Visitor Engagement and Museum Technology, were offered the opportunity to receive extra credit in the class if they handled my visor and took the same survey that was offered to visitors at the RMSC.[50] Since the original visor was not accessible for this study, an image of the real visor was available for students to look at while handling the facsimile. The survey these students took was the same as the one the RMSC visitors took, however, the demographics section was removed since all the students taking the survey were of the same age range and education level, and the questions about their museum visit were not relevant. Students who answered the preliminary study were not included in the drawing for the Amazon gift cards.

The data gathered from the students in this class was positive and suggested that the visitors at the RMSC might react well to the visor (See Appendix A, Figure 2 for a full copy of the preliminary data). Fourteen students ended up completing the survey, and all fourteen selected at least one answer for question one, regarding the types of objects visitors might desire to touch in museums. The most popular choice was hands-on exhibits, which eleven students (78.6%) selected, and the least popular was animal specimens, which three students (21.4%) selected. The second question regarding a desire to touch the snow visor, or another similar object was less conclusive, with four students (28.6%) each rating their desire a "3" and "5," and three rating it a "4" (21.4%). This suggested that although a general desire to touch museum

[50] This course is a museum studies elective course taught by Dr. Juilee Decker who is also an advisor on this thesis. There is no prerequisite for this course and enrollment during this semester (Spring 2019) consisted of students from seven colleges in the university.

objects might exist, it may not have existed for this object. However, it is also a different experience viewing an image of an object versus seeing it in person, and that might have affected the responses to this question.

The third question, which asked the students to rate if touching the surrogate snow visor fulfilled their desire to touch the original, provided interesting data. Four students (28.6%) rated their fulfillment a "5," while three rated it a "4" (21.4%). Students had been asked to respond with "1" to this question if they had responded with "1" to the previous one, and both questions received two responses for "1" (14.3%). Assuming that all students followed the directions, we can assume that that students who originally expressed a desire to touch the original snow visor rated their fulfillment of this desire a "3" at the lowest, with "2" receiving no responses, and "3" receiving five (35.7%). Although this data did not suggest a strong fulfillment of the desire to touch, it did show promise for the RMSC study to be successful.

The question about visitor enjoyment did very well in the preliminary student study, with seven students (50%) rating their enjoyment a "5," three students (21.4%) rating it a "4," and the final four students rating it a "3" (28.6%). This showed that even if the replica visor did not completely fulfil the student's desires to touch the original object, the experience was nonetheless enjoyable.

The questions where visitors had an option to leave a short answer provided some insight into the responses given. In the first short answer following the question about the visor fulfilling the desire to touch, a student responded, "It fulfilled the desire of the tactile curiosity of the

shape and feel of the object, but not the object authenticity."[51] This was echoed in another answer,

> "It didn't completely fulfill the desire, because the surrogate doesn't have as much 'historical weight' or whatever. Like, the actual item was actually worn by the people that originally made it, so holding it would feel like a closer connection to the native people. But given that I'd never otherwise have the opportunity to touch it, it was much closer than I have previously gotten."[52]

These responses provided helpful insight into how the students felt about the replica, as well as to the types of touch it addressed. It also gave me a sense of the answers I might expect once I conducted the real study at the RMSC, and the shortcomings and successes the visor might have.

Changes to the Study

User testing was conducted over a period of three days at the Rochester Museum and Science Center. The testing occurred in February 2019, to coincide with the municipal school district February break, which usually results in higher visitorship at the RMSC than average during the week.

The original setup described in the previous section was used throughout the process, however, some amendments were made to ensure enough visitors completed the experience and survey. After initial observations, I noticed that parents seemed reluctant to allow their children to handle the visor, although the children were interested in it. To combat this, a second vinyl

[51] Carr, Elizabeth. "Visitor Study: MUSE 360 Data," *RIT Museum Studies Program*, unpublished work, March 7, 2019.
[52] Carr, Visitor Study: MUSE 360 Data."

label was added to the pedestal telling visitors that it was okay to touch the visor (see Figure 28). Additionally, after a low turnout rate the first day of observations, announcements were made by the RMSC staff over the intercom system throughout the second and third days to alert visitors to the survey's existence. These announcements were followed by a significant increase in visitors wishing to participate in the survey.

Although the main source of information for this study was the survey visitors completed after interacting with the object, I also tracked visitor information while observing interactions and making sure the setup was not damaged (See Appendix A, Figure 3 for a copy of my observation notes). In my notes, I tracked the number of visitors who stopped at the object or seemed to express interest in it, the number who handled the visor, and the number who tried it on. Although many people stopped to look at the object, not all visitors handled it (47% of observed visitors touched the visor), and even fewer tried it on (34% of observed visitors). I also observed many visitors try the visor on incorrectly, such as wearing it so the nose hole was against the forehead, or several small children who attempted to wear the visor as if it were a shoe.

My original idea was to observe the visitors without engaging with them, however, this strategy changed after the first day of observations. My goal was had been to have between one hundred to 200 total respondents, however, I only had fourteen at the end of the first day. Because of this, I took a more active approach on the other two days and encouraged visitors who stopped at the visor to take the survey that was displayed on the nearby iPad. I also helped facilitate several of the interactions by explaining the facsimile to visitors and pointing out the original visor, however, I tried to save these explanations until after the visitor had completed the survey. By the end of the three days, I had received seventy-one responses to the survey. While

this number was less than I had anticipated, I was hopeful that the data would still prove to be useful.

Visitor Responses

After looking at the survey data, some trends began to emerge among visitor responses (See Appendix A, Figure 4 for a copy of the survey data). For my first question about the different types of objects a visitor might desire to touch, visitors overwhelmingly demonstrated that they did want to touch museum objects. Only four of the seventy-one visitors selected the option "I never have a desire to touch museum objects," while all other options received a high number of selections.[53] The most popular object was "hands-on exhibits," which fifty-four visitors selected (76% of visitors), and the least popular was "Historic documents/manuscripts," which seventeen selected (23.9% of visitors). All other categories performed well, leading me to conclude that museum visitors do have desires to touch different types of museum objects. I found this to be significant, since it supports much of the scholarship I reviewed during the touch section of my literature review and demonstrates a need for museums to consider the role of touch as important to their visitors.

Continuing with this idea, the second question in the study demonstrated that visitors did have a desire to touch the snow visor or another similar object prior to the experience they had with the facsimile. Out of seventy-one visitors, twenty-two (31%) rated their desire a "5," and nineteen visitors (26.8%) rated it a "4." Combined, this means that forty-one visitors (57.7%) had a strong desire to touch the snow visor prior to handling it. In addition to this, only six visitors

[53] Technically, five visitors selected the option "I never have a desire to touch museum objects." However, one of these visitors picked every type of object as well as this option, leading me to believe that it was selected accidentally while picking all other options. Thus, I have removed one response from this choice.

(8.5%) rated their desire a “1,” further showing that among most visitors, there was a strong desire to touch the objects.

As a follow-up to this question, visitors were asked to rate whether the facsimile snow visor fulfilled their desire to touch the original. Again, the majority of visitors rated their fulfillment a “4” or “5,” with twenty-four of the seventy-one visitors (33.8%) responding “4,” and seventeen (23.9%) rating it a “5.” Although this means that the majority of visitors rated their fulfilment as a “4” rather than a “5,” it does demonstrate that most visitors (41 total, or 57.7%) found the facsimile visor fulfilling their desire to touch the real object. This is especially significant, since only eight (11.3%) of visitors rated their fulfillment a “1.” Visitors had been asked to answer “1” here if their response to the previous question was also “1,” and assuming all visitors followed these directions, it means that only two visitors (2.8%) had a previous desire to touch the object and found that the facsimile was completely unsatisfying.

The majority of visitors (53.5%) found that the texture of the replica matched their expectations. A significant number responded that they were not sure if it matched their expectations (21.1%), and roughly a quarter of visitors (25.4%) found that it did not match their expectations. I found this data interesting, because the texture of the visor ended up being different than what I had originally intended for it. I was planning on the visor being the smooth, almost slippery texture of printed PLA, which is very different from that of the original wooden snow visor. However, the sanding and painting processes affected the texture of the visor, making it feel less like plastic and giving it more texture than the smooth plastic had. Although unintended, this also made the visor look more like wood, which was the material of the original object. This might have impacted the way visitors felt about the replica compared to the original object, but this cannot be proven given the survey data.

Finally, visitors overwhelmingly responded that they enjoyed the experience of touching the snow visor. Thirty-two of the seventy-one visitors (45.1%) rated their enjoyment of the experience as a "5," fifteen visitors (21.1%) rated it as a "3," and another fifteen (21.1%) rated it a "4." Only three visitors (4.2%) rated their enjoyment of the experience as a "1." This suggests that although not all visitors found the snow visor to be fulfilling of their desire to touch, the vast majority of visitors did find their experience enjoyable.

In addition to these questions, visitors were given the opportunity to further explain why they found the visor fulfilling or not fulfilling, as well as to leave additional comments at the end of the survey. These comments proved insightful, with many of them talking about the experience or how it was different from what they expected. In response to the first short answer, regarding why the visor was or was not fulfilling, one visitor commented "Yes because it let me experience the history of the Native Americans and see what it was really like," while another said "It was really neat to try it on and see how everything looked from the inside."[54] Both visitors found the experience fulfilling, because it gave them a new perspective by allowing them hands-on interaction with an object that would normally be off-limits to visitors. This sentiment was echoed in the second short answer, which provided an opportunity for further comments, with responses such as "It was a unique experience," "I appreciate the opportunity to experience something I otherwise wouldn't in my daily life," and "I like being able to touch things, because it allows you to get a sense off the purpose and material used."[55]

Since the demographic data was used only to get a sense of the people who responded to the survey, I do not believe it is relevant to explain that data in detail. Many of those who

[54] Carr, Elizabeth. "Visitor Study: RMSC Data," *RIT Museum Studies Program*, unpublished work, February 23, 2019.
[55] Carr, "Visitor Study: RMSC Data."

completed the survey were children and were visiting the museum with either one other person, or in a group of six or more people. This does suggest that one survey might have been filled out by multiple visitors that were part of the same group, however, that does not affect the responses that were given in any way that can be determined by looking at the data.

Findings

After conducting this visitor study and analyzing the data, it has been demonstrated that an accurate 3D model of a museum object can serve as a satisfying replica in fulfilling the desire of visitors to touch the original object. The majority of survey respondents felt the replica object was successful in fulfilling their desire to touch the original snow visor, and a similar number of visitors felt that it matched their expectations in terms of texture.

In addition to these conclusions, this study also found that visitors overwhelmingly have a desire to touch the items they encounter in museums. This suggests a need for museums to investigate ways that this desire can be fulfilled, whether through facsimiles, teaching collections, or hands-on experiences. Ultimately, museums are not serving their purpose if patrons are leaving unsatisfied with the experience they had and providing tactile experiences can be a way for visitors to feel more engaged with the material.

Even for visitors who did not have a desire to touch the original object, or those who found the experience unfulfilling, most visitors still reported enjoyment from the experience that they had with the visor. This shows that hands-on experiences are enjoyable for visitors even if it is not fulfilling its intended purpose. Just as a visitor can use and enjoy a hands-on exhibit without completely understanding the concepts behind it, they can enjoy a facsimile even if it

does not meet its intended goal of fulfilling their desire to touch the original object. Because of this, I believe that these experiences are a vital part of a museum visit and are important to have available for visitors to interact with and learn from.

Conclusion

By nature, humans have a desire to touch the things they encounter in daily life. We are tactile beings, and touch can be used to give us information about the world surrounding us. This can be a problem for museums, which often do not allow the handling of their objects by the public. Despite this, museum visitors seek interactive experiences, and unauthorized touch is a widespread problem for cultural institutions.

Facsimiles can provide a way for visitors to have the tactile experience they desire when they visit museums, without the safety of the real object being compromised. This is important for understanding the visitors' expectations and trying to provide the experience they want to have while still fulfilling the needs of the institution. As stewards of cultural heritage, museums have a responsibility to keep their collections items safe and preserve them for the future. At the same time, however, they have a responsibility to their visitors to provide them with an educational, fulfilling experience. When being able to touch objects can provide this experience, it seems only right for the museum to work to provide it.

With the proliferation of technology such as 3D printing, it is not unreasonable for museums to provide their visitors with the opportunity to handle accurate models of collections objects. With time and dedication, the software and skills needed to work this technology can be learned, and accurate facsimiles of collections items can be created with relative ease. Especially since 3D scanning objects does not require any physical stress to be placed on them, it is both a practical and effective way to create accurate facsimiles of collections objects. 3D printing is a feasible option for museums looking to engage their visitors further and should be investigated as a way to help provide them with the experience they are looking for.

This thesis has demonstrated that accurate 3D printed facsimiles can be used successfully to fulfill the desire of visitors to touch museum objects. With the right tools and knowledge, this process can be easy, inexpensive, and satisfying for the visitors who get to interact with collections objects in a new way. Even for visitors who did not find the model to be satisfying, the experience was still enjoyable, showing that the facsimiles can fulfill a purpose even if it is not the intended one. 3D printing technology can allow visitors to interact with collections in a way they never have before and fulfill desires that have previously been unable to be satisfied without damage to the object. Museums should be taking advantage of these technologies in order to provide visitors with the tactile experience that they desire.

Figures

Figure 1 and Figure 2: Wooden snow visor on display at the Rochester Museum and Science Center (RMSC). The original item contains a strap that was not recreated with scanning. Both images courtesy of Elizabeth Pietrzykowski.

Figure 3: Cardboard model of the visor. This model was constructed in order to practice scanning before going to the RMSC. Image courtesy of author.

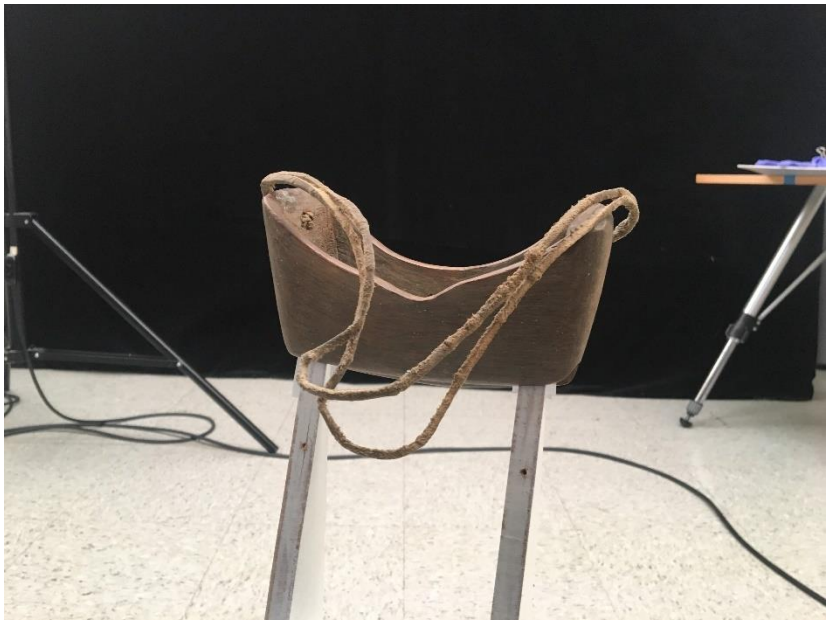


Figure 4 and Figure 5: Wooden snow visor in position for scanning. The visor was placed on a piece of wood with two thin arms extending from the base. The two arms were placed through the slit at the front of the visor, where it rested safely while being scanned. Both images courtesy of author.

Figure 6: Author scanning the visor. The visor was scanned using a Structure Sensor iPad attachment. The model of the scanned visor appears in white on the iPad screen. Image courtesy of Jade Myers.

Figure 7: Snow visor being measured. Using calipers, different parts of the visor were measured after the scanning process was completed. This allowed for the scale of the visor to be checked once the models were made. Image courtesy of Jade Myers.

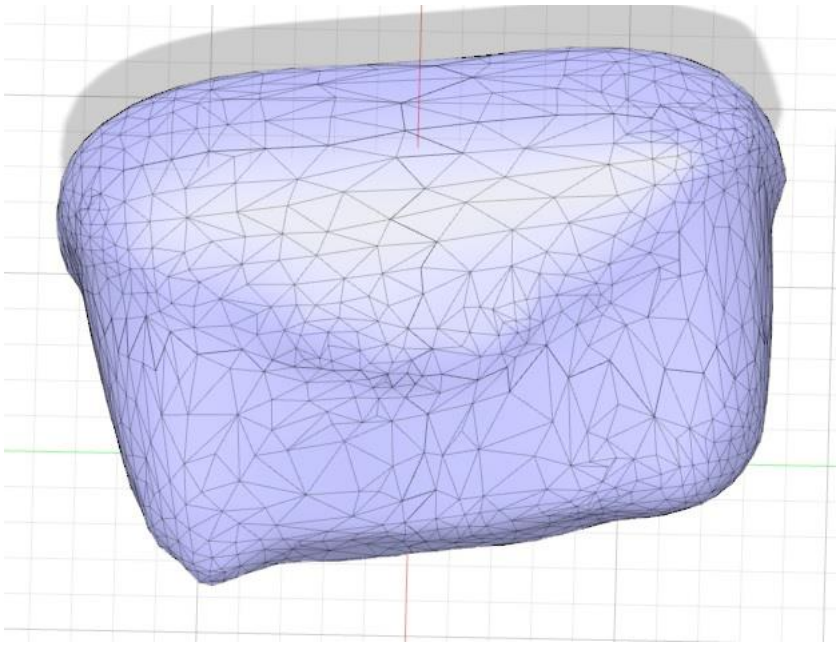


Figure 8: Image of the scanned visor after being exported. The scanner struggled to capture the open back of the visor and filled it in with a large piece of excess material, seen at the top of the image. Image courtesy of author.

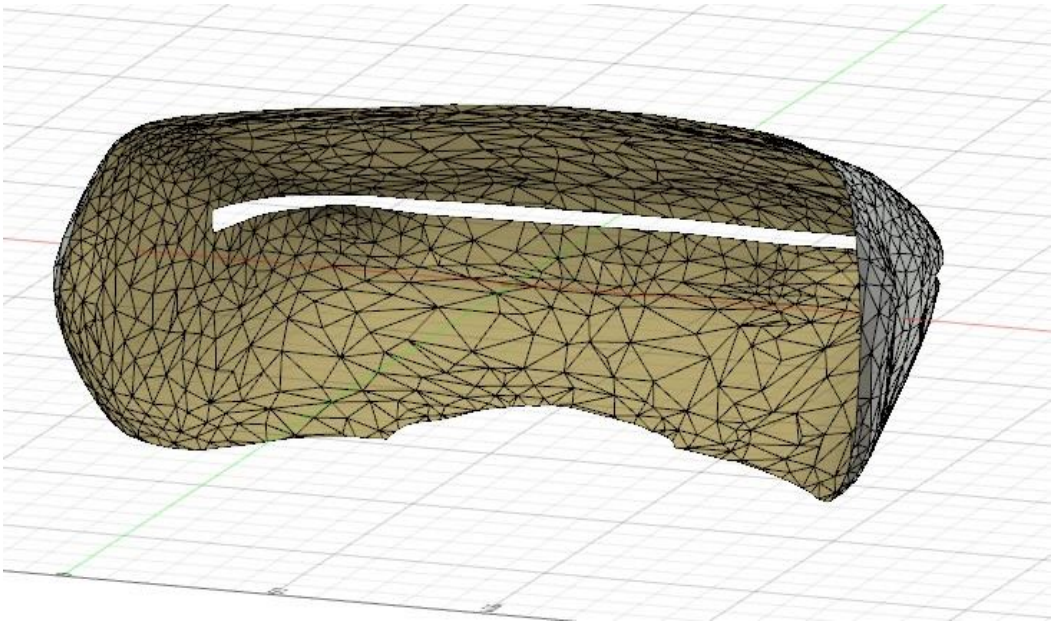


Figure 9: Visor model after processing. The nose hole of the visor is seen at the bottom, and the slit is seen at the back. Image courtesy of author.

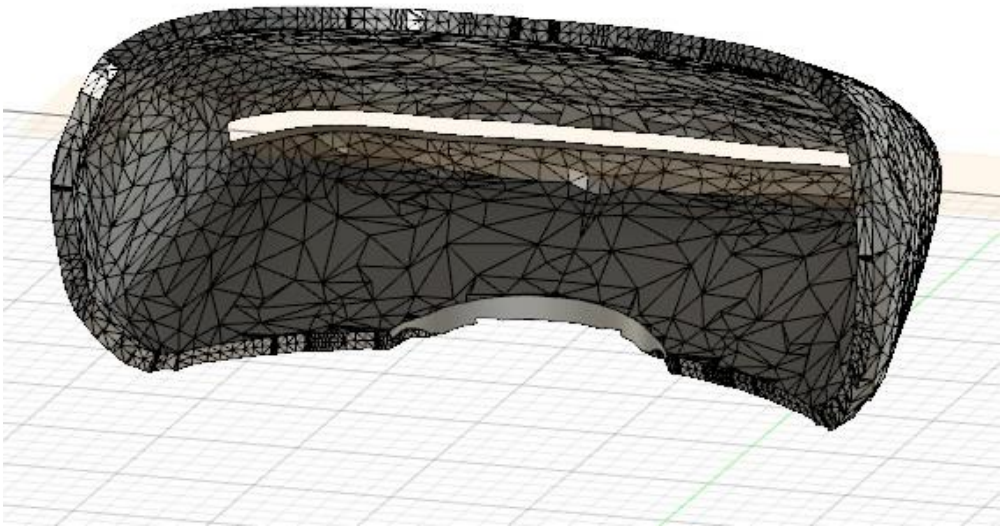


Figure 10: First complete model of visor. This model was used to create the first test print of the snow visor. It now has a thickness, unlike in the previous figure. Image courtesy of author.

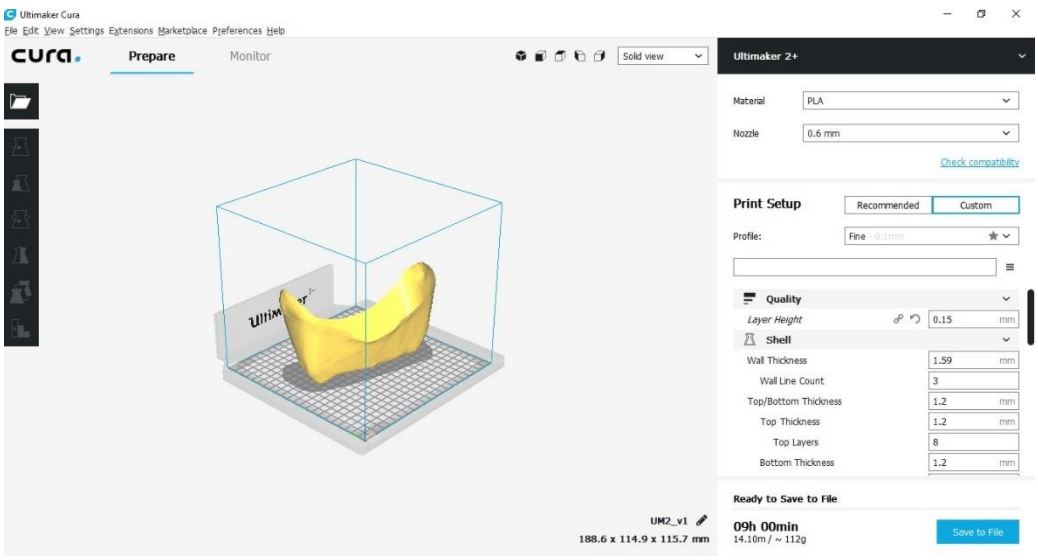


Figure 11: Model in Cura. Using the software Cura, print settings were determined and the placement of the model on the print bed was set. Image courtesy of author.

Figure 12: Test print with brim and supports. Pieces of excess material are printed on the bottom of the base (brim), as well as going up from the brim to support the print (supports). These pieces are broken off after printing and discarded. Image courtesy of author.

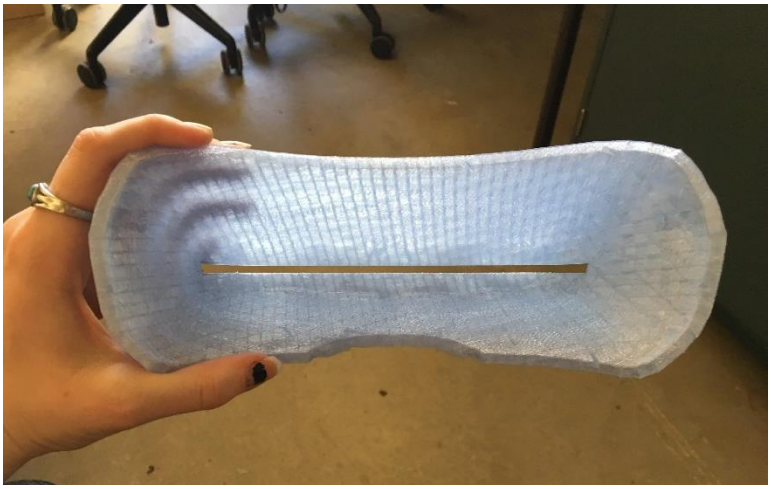


Figure 13 and Figure 14: First test print after printing. This print was done in clear/blue PLA and had some flaws that were remedied in the second print. Both images courtesy of author.

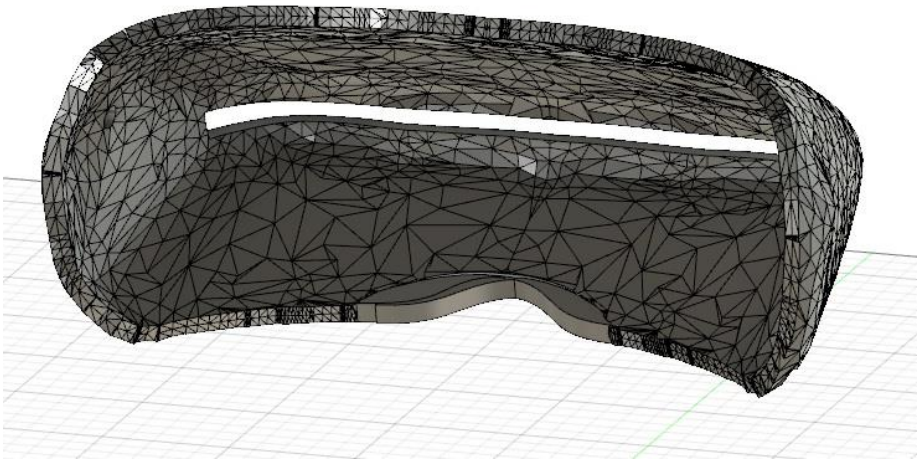


Figure 15: Second complete model of visor. For the second print, the nose hole shape was adjusted, and the print was scaled down. Image courtesy of author.

Figure 16 and Figure 17: Second test print after printing. The second test print was much closer in size to the original visor, and the nose hole was a much better shape. Both images courtesy of author.

Figure 18: Brim on the final print. The excess material at the bottom of the print needed to be removed, as it was only there to provide support during printing. It was removed first with pliers, then a chisel, and finally with sandpaper. Image courtesy of author.

Figure 19: Visor after brim was removed. Not all of the brim could be removed, as part of it made up the edge of the visor. This edge was later sanded and painted so as to not stand out. Image courtesy of author.

Figure 20: Visor during sanding process. Physical defects such as uneven areas, sharp edges, and the excess brim were removed with sanding. Image courtesy of author.

Figure 21: Visor after sanding process. The sanding process removed many of the physical defects that the print had, but also discolored the sanded areas. Image courtesy of author.

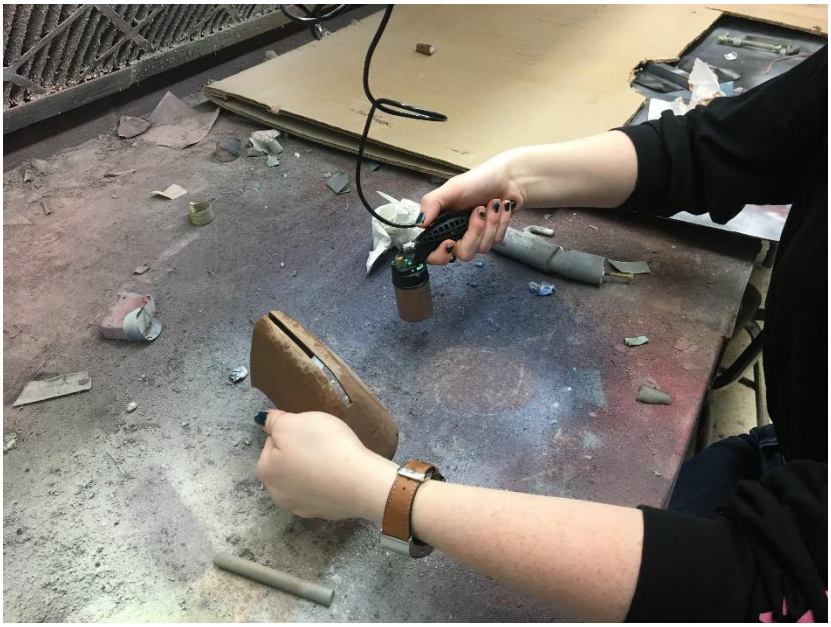


Figure 22: Author airbrush painting the model. The visor was airbrush painted brown after the sanding process to even out the color. Inadvertently, this also made the print look and feel more like wood, the material of the original visor. Image courtesy of John Lyons.

Figure 23: Completed model of the snow visor. After the airbrush process was done, the final print of the visor was completed. The paint did not completely fix the discoloring caused by sanding, however, it was even enough to be acceptable for testing. Image courtesy of author.

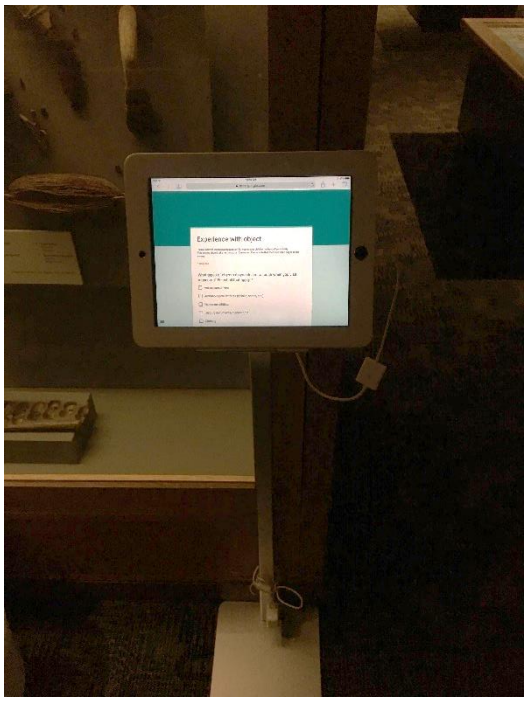


Figure 24: iPad and Stand. An iPad was available next to the model at the RMSC for visitors to take a survey about their experience. Image courtesy of author.

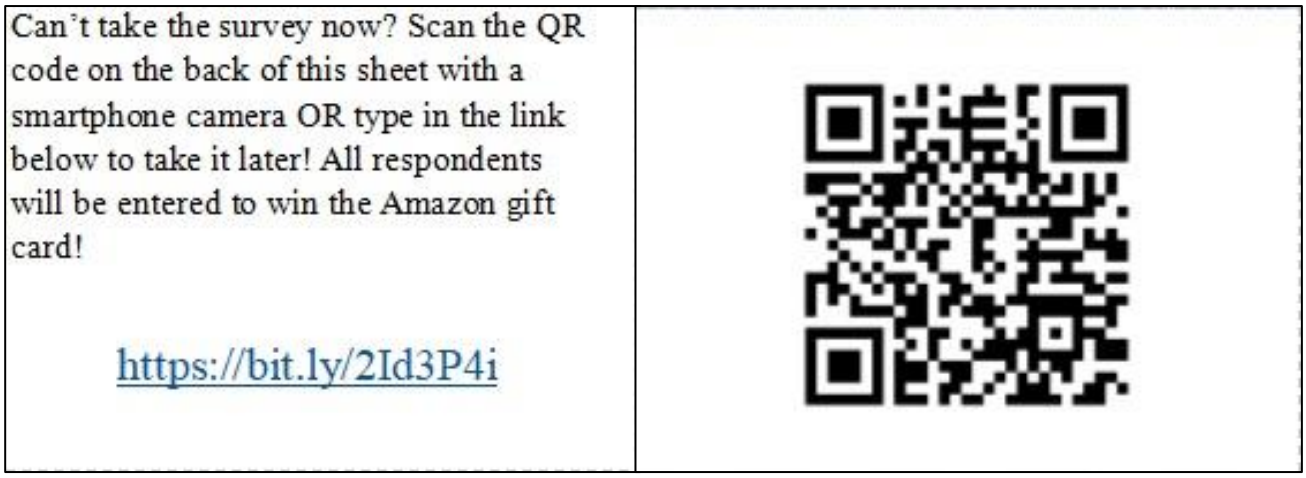


Figure 25: Slips of paper with link to survey. For visitors who could not take the survey at the RMSC, slips of paper were available to take home so the survey could be completed later. The text on the front and the QR code were printed back to front, with the link bringing you to the same survey as the QR code. Image courtesy of author.

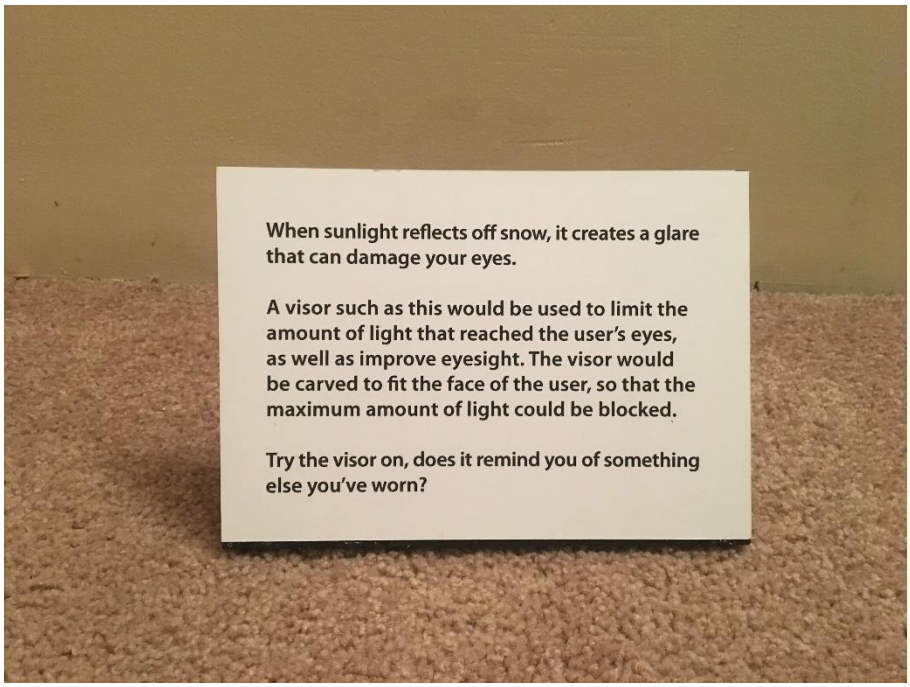


Figure 26: Label copy about the visor. This label, which was written by the author and edited and printed by RMSC staff, was placed on the pedestal to provide additional information about the visor to visitors. Image courtesy of author.

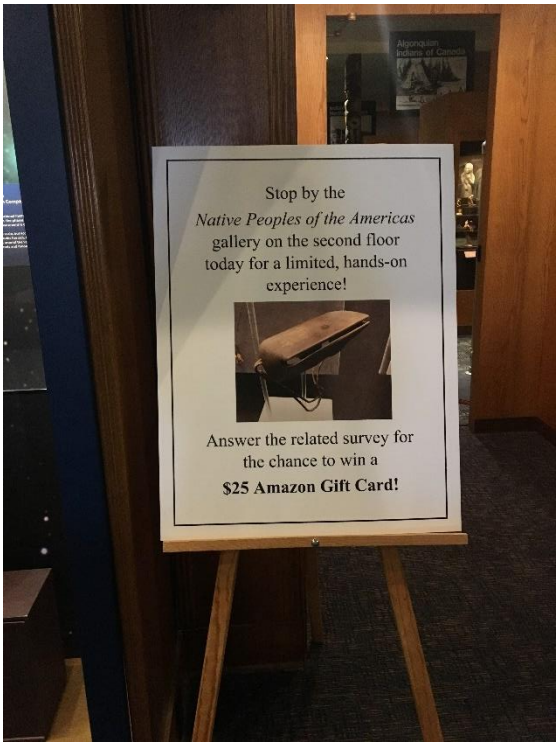


Figure 27: Easel poster advertising the study. Two large easels were placed in the museum to advertise the study to visitors. Image courtesy of author.

Figure 28: Original setup at RMSC. All items were placed on a museum-provided pedestal in front of the original visor, which can be seen in the case behind the hand sanitizer. A trashcan was placed to the right of the pedestal, and the iPad was placed at the far right so that it would not block any of the objects on display. Image courtesy of author.

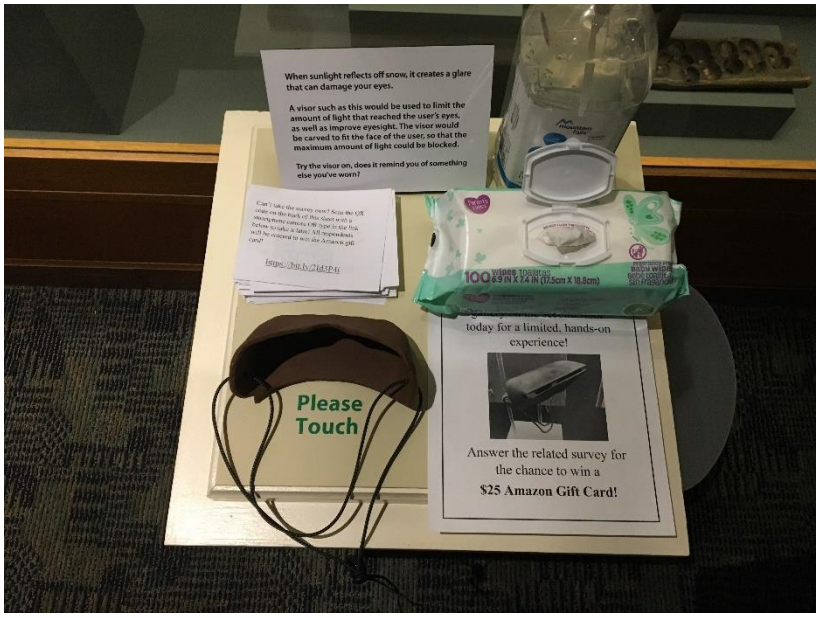


Figure 29: Updated setup at RMSC. After initial observations, a "PLEASE TOUCH" label was added to alert visitors that the object could be handled. A flyer was also placed on the pedestal so that visitors would know what the setup was for. Image courtesy of author.

Appendix A: Forms

Figure 1: Blank visitor survey

Experience with object

Please answer the following question for you or your child to the best of your ability
This survey should take no more than 2 minutes. Please note that there are three pages to the survey.

* Required

1. **What types of objects do you desire to touch when you visit museums? Select all that apply.** *
   Check all that apply.

   - [ ] Animal specimens
   - [ ] Archaeological artifacts (fossils, bones, etc.)
   - [ ] Hands-on exhibits
   - [ ] Historic documents/manuscripts
   - [ ] Clothing
   - [ ] Objects with historic value
   - [ ] Paintings
   - [ ] Sculptures
   - [ ] I never have a desire to touch museum objects
   - [ ] Other: _____

2. **Did you have a desire to touch the snow visor or another similar object prior to this experience?** *
   Mark only one oval.

	1	2	3	4	5	
Absolutely no desire	◯	◯	◯	◯	◯	Very strong desire

3. **Did touching the snow visor fulfill this desire to touch? If you did not have a desire to touch the visor, please select "1."** *
   Mark only one oval.

	1	2	3	4	5	
Absolutely did not fulfill	◯	◯	◯	◯	◯	Completely fulfilled

4. **Why or why not? (optional)**

_____

_____

_____

_____

_____

5. **Did the texture of the replica match your expectations?** *
   Mark only one oval.

   - ◯ Yes
   - ◯ No
   - ◯ Not sure

6. **Overall, did you enjoy touching the snow visor?** *
   Mark only one oval.

	1	2	3	4	5	
Absolutely did not enjoy	◯	◯	◯	◯	◯	Very much enjoyed

7. **Is there anything else you would like to share about your experience with this exhibit? (Optional)**

Demographic information

This section is optional, and is for informational purposes only. Your responses to this section will not be connected to your responses in the previous section.

8. **What is your age range, or the age range of the person you are taking this survey for?** *
   Check all that apply.

   - ☐ Under 12
   - ☐ 12-18
   - ☐ 18-24
   - ☐ 25-32
   - ☐ 33-45
   - ☐ 46-55
   - ☐ 55-65
   - ☐ Over 65

9. **What is your highest level of education?** *
Mark only one oval.

- ◯ Kindergarten - 5th Grade
- ◯ 6th Grade - 9th Grade
- ◯ 10th Grade - 12th Grade
- ◯ High School Diploma
- ◯ Some College
- ◯ Associate's Degree
- ◯ Bachelor's Degree
- ◯ Graduate Degree (Master's or Ph.D)

10. **Who did you visit the museum with today?** *
Mark only one oval.

- ◯ My child/children
- ◯ A child/children under my care (I am a babysitter, caregiver, grandparent, etc)
- ◯ My parent(s)
- ◯ Other family members who are not my parents
- ◯ My friends
- ◯ Alone

11. **How many people did you visit with today (including yourself)?** *
Mark only one oval.

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6 or more

Contact information

If you would like to be entered for a chance to win a $25 Amazon gift card, please enter your contact information below. Your information will not be linked at all to your survey answers, and will not be shared with anyone. All contact information will be discarded after the completion of this study. If you do not want to enter, please select "SUBMIT."

12. **Name**

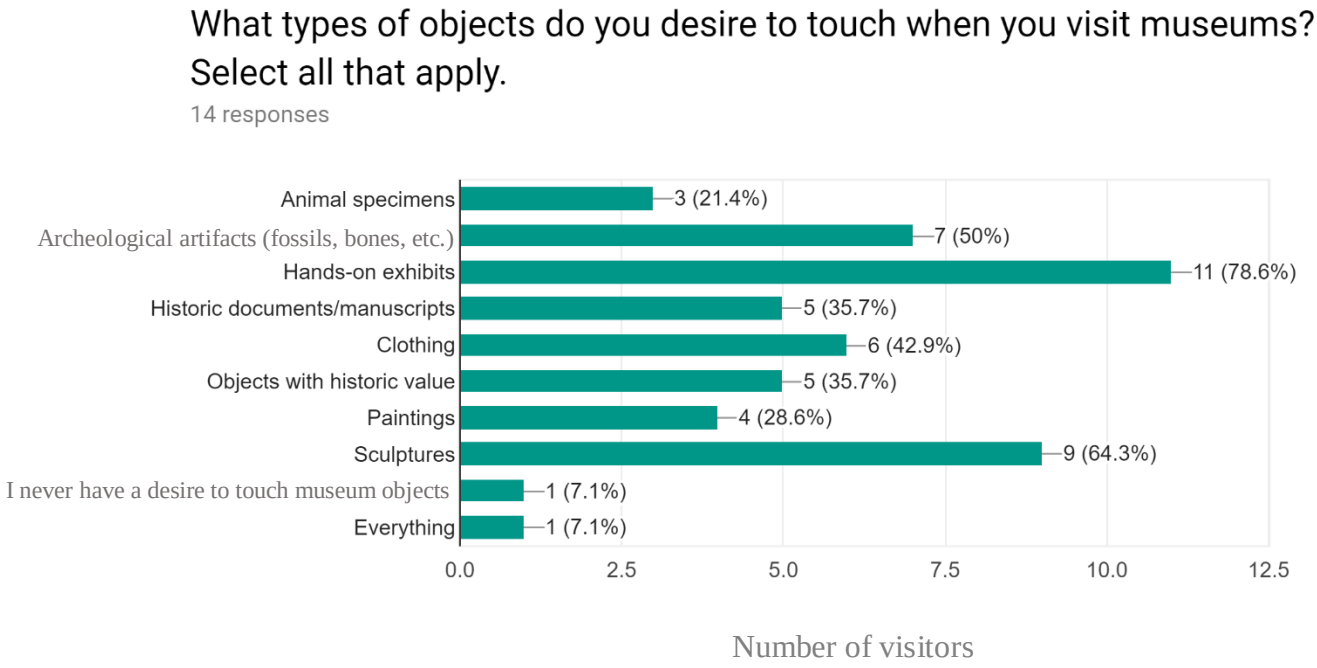
_____

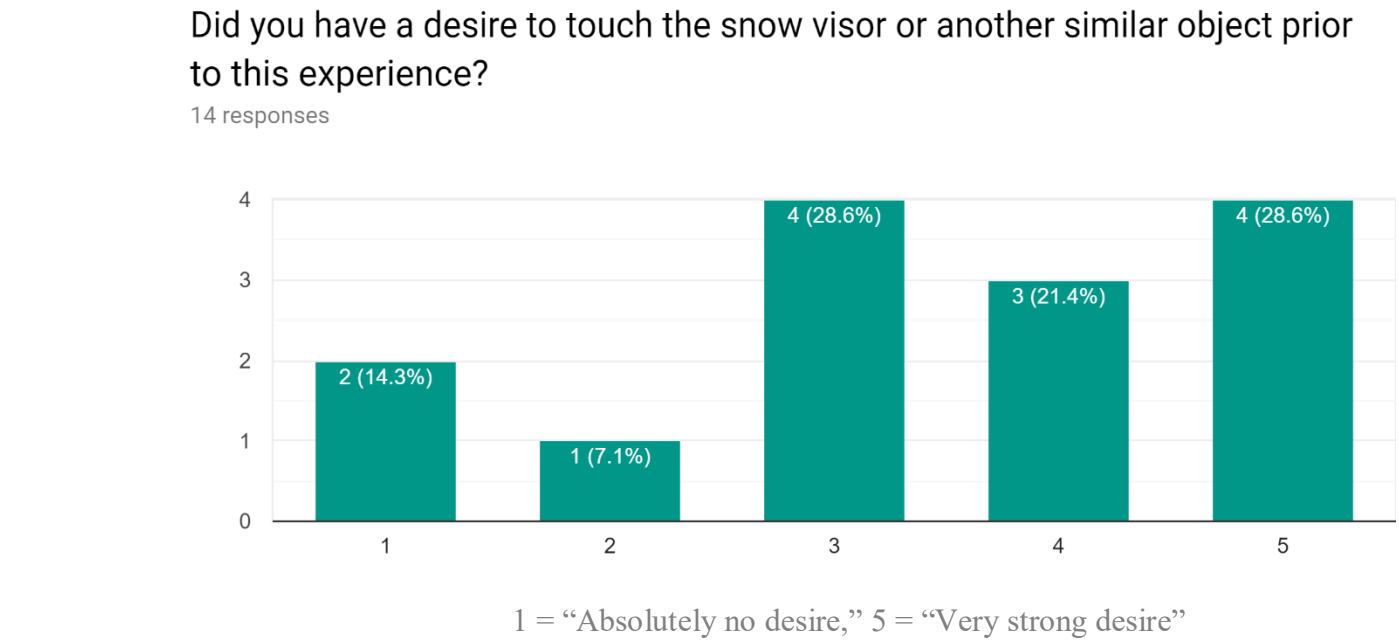
13. **Email Address**

_____

Figure 2: Data from preliminary study with RIT students

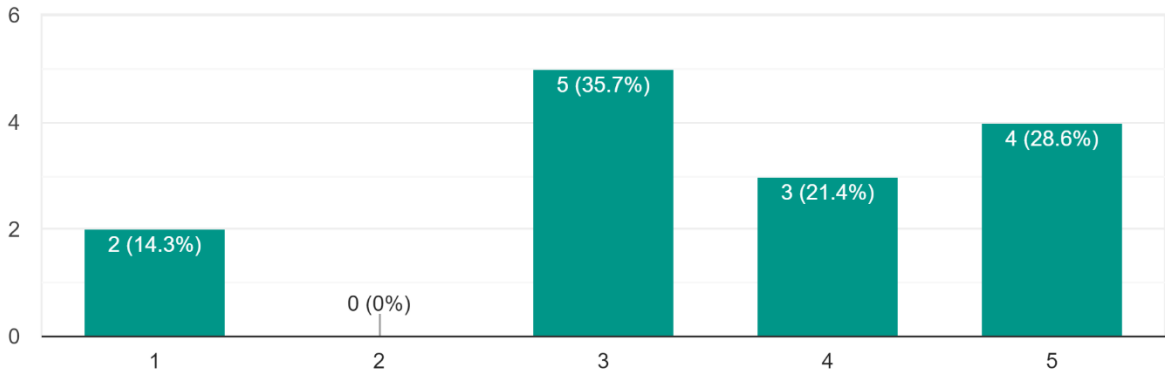
Note: identifying information such as names and email addresses are not included in this data in order to protect respondents' anonymity





Did touching the surrogate snow visor fulfill this desire to touch? If you did not have a desire to touch the visor, please select "1."

14 responses



1 = “Absolutely did not fulfill,” 5 = “Completely fulfilled”

Why or why not? (optional) 9 responses

It fulfilled the desire of the tactile curiosity of the shape and feel of the object, but not the object authenticity.

It didn't completely fulfill the desire, because the surrogate doesn't have as much "historical weight" or whatever. Like, the actual item was actually worn by the people that originally made it, so holding it would feel like a closer connection to the native people. But given that I'd never otherwise have the opportunity to touch it, it was much closer than I have previously gotten.

Let me understand how it looked instead of inferring

It takes it a step further when you can put on an object rather than just touch it.

It looks just like it!!!!!

I'm a hands on person

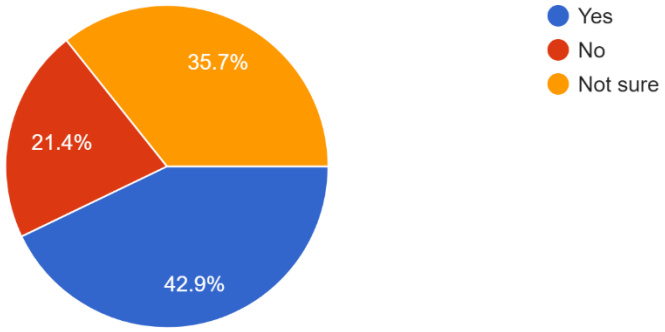
It's a really great print

The texture is not tempting.

Seeing the range of field of view was really neat

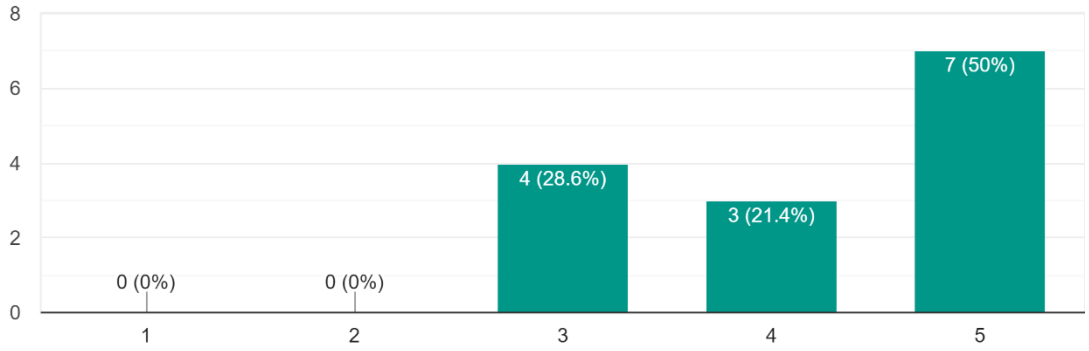
Did the texture of the surrogate match your expectations?

14 responses



Overall, did you enjoy touching the snow visor?

14 responses



1 = “Absolutely did not enjoy,” 5 = “Very much enjoyed”

Is there anything else you would like to share about your experience with this user testing? (Optional) 4 responses

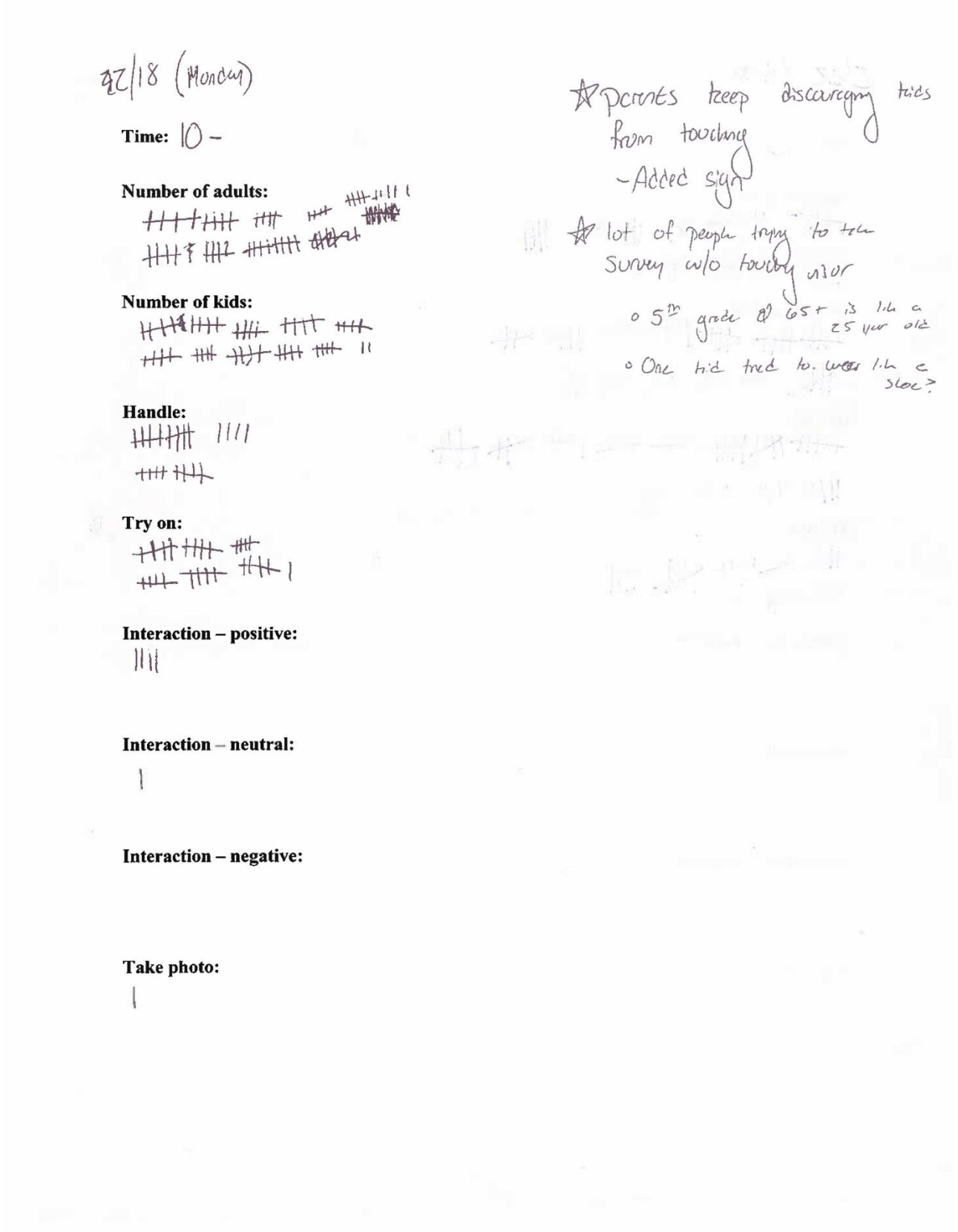
When I wear this object, it kind of uncomfortable because I wear the glass, but overall this is cool for me really touch the staff usually out in the glass that we can't touch.

I feel like the object might feel more wooden? But I understand that 3D printed things are plastic.

Super cool project !!!!

It didn't feel like a 3D print with the paint used (that said, it didn't feel like wood but it's plenty good for me). Good job

Figure 3: Copy of Observation Notes



2/22 (Friday)

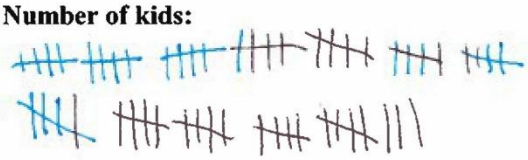
~7 - "I want to teach staff"

Time: 10 -

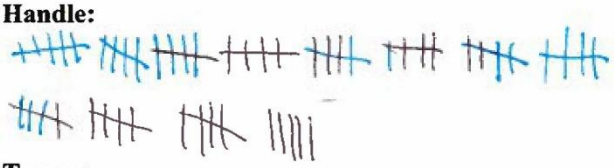
Announcement over 12:45

Number of adults:

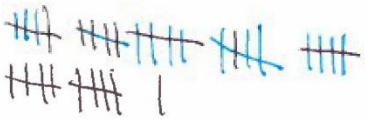
Number of kids:



Handle:



Try on:



Interaction – positive:

Interaction – neutral:

Interaction – negative:

Take photo:

2/23

Time: 10-

Number of adults:

Number of kids:

Handle:

Try on:

Interaction – positive:

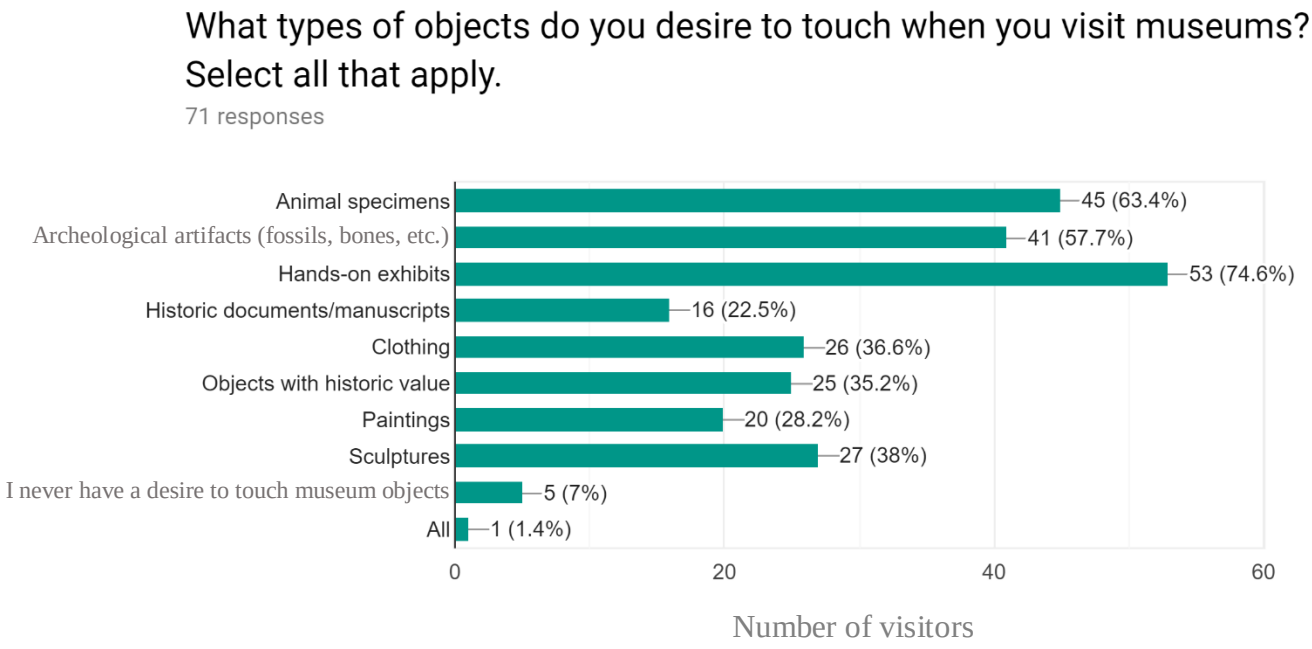
Interaction – neutral:

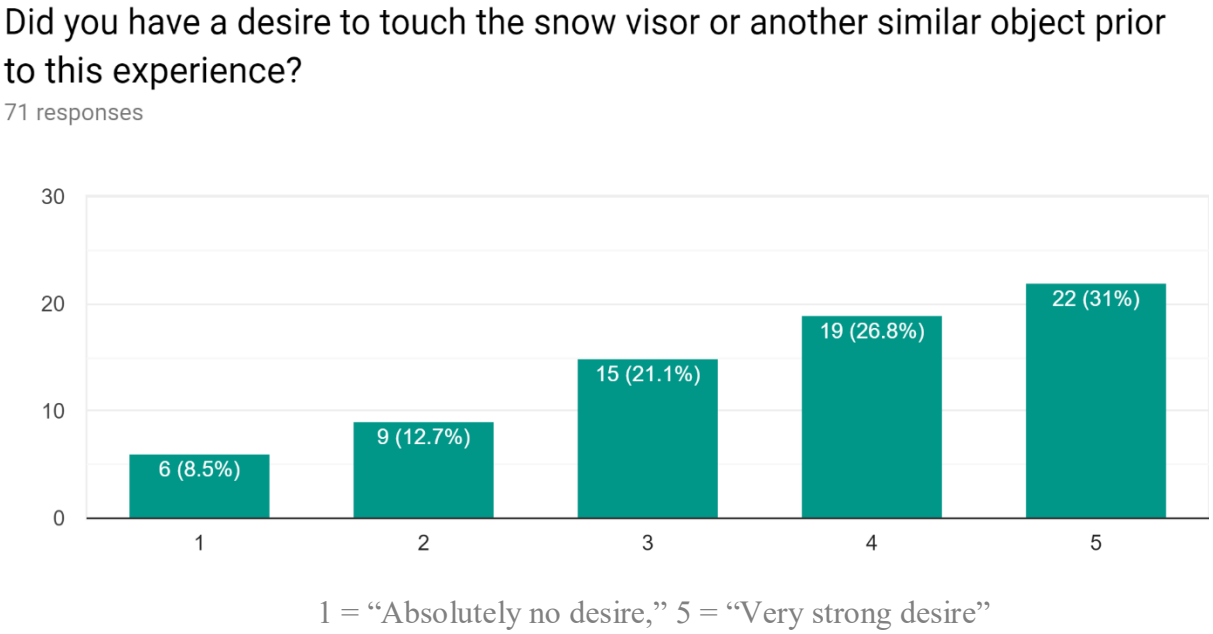
Interaction – negative:

Take photo:

Figure 4: Data from visitors to the Rochester Museum and Science Center

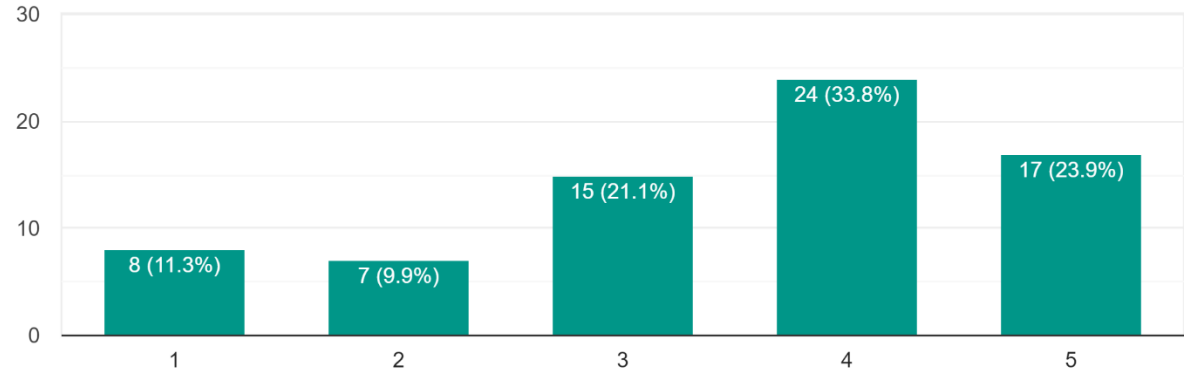
Note: identifying information such as names and email addresses are not included in this data in order to protect respondent's anonymity





Did touching the snow visor fulfill this desire to touch? If you did not have a desire to touch the visor, please select "1."

71 responses



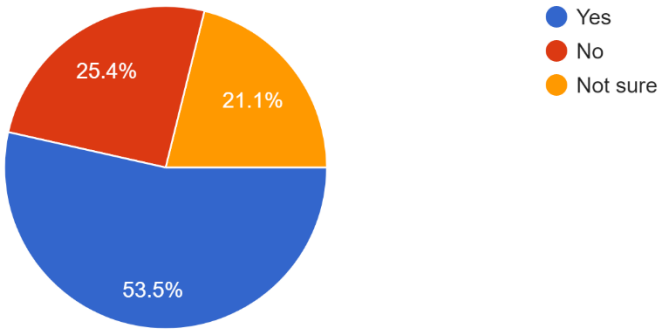
1 = “Absolutely did not fulfill,” 5 = “Completely fulfilled”

Why or why not? (optional) 23 responses

I would like to touch it all.
It. Was interesting to see how they would limit the light
Not real
I have a high maturity level
A mask
Amask
Snow visors are sorta boring no offense
I'd never seen one before
Didn't really feel the need anyway
ADHD, it makes it more fun. But as a person without ADHD, I just also enjoy touching things.
Yes because it let me experience the history of the Native Americans and to see what it was really like.
Becouse it felt very ancient.
It was really neat to try it on and see how everything looked from the inside.
It is a tool for health and safety
It was hardy then I thought
Cool to look at the light change.
I did only want to see the composition of the reconstruction
Aaaaa
It's plastic
Me when fmyce
Yes, it was stimulating to feel the snow visor.
It fulfilled my desire because i crave contact with inanimate objects

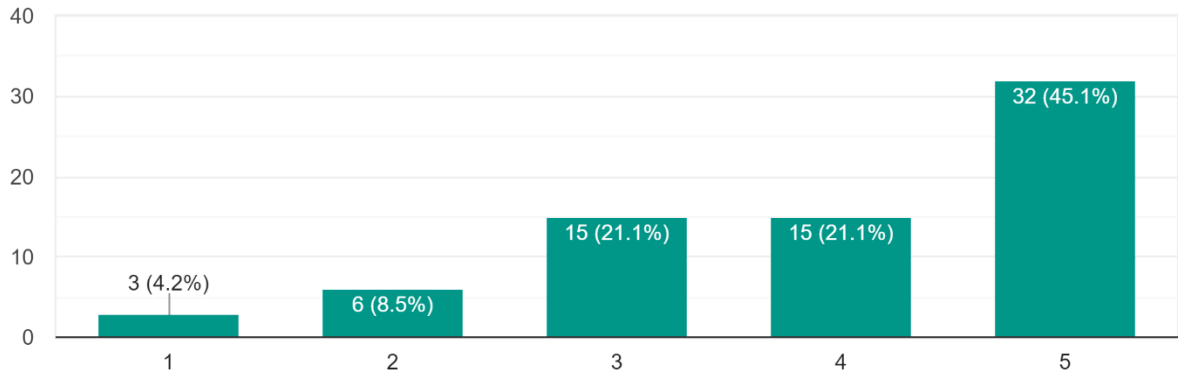
Did the texture of the replica match your expectations?

71 responses



Overall, did you enjoy touching the snow visor?

71 responses



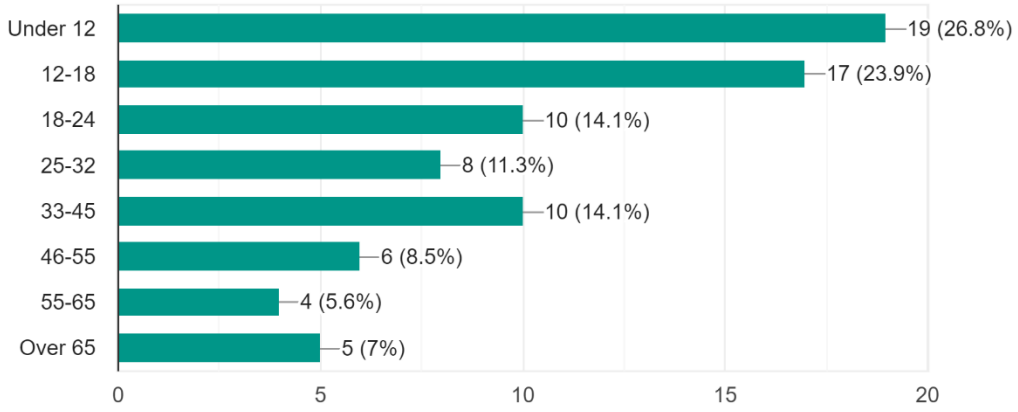
1 = “Absolutely did not enjoy,” 5 = “Very much enjoyed”

Is there anything else you would like to share about your experience with this exhibit? (Optional) 24 responses

Trying it on is really cool! This could be turned into a cool exhibit if guests looked at something bright while trying it on. PS- I work here so no need to put my survey in the running for a gift card :)
I want to touch a fox
It was a unique experience
Some things looked cool
So many things to be thankful with this morning
It would have been cool to have a bright "snow" area to look at to experience how the visor helps.
It's a very well place to have fun and learn
I appreciate the opportunity to experience something I otherwise wouldn't in my daily life
No
It needs more cowbell.
I loved this exhibit because I have a lot of background knowledge from elementary school
No thank you
It was really neat to be able to try the visor out!
I felt transported back to the time
Very cool
No.
Idk
I like being able to touch things, because it allows you to get a sense of the purpose and material used
It's cool I love it in theory
The Native Peoples exhibit is one of my favorites because it is so interactive, yet not at the same time.
I like the replicas of Native Americans building things and rowing.
I really like your snow visor, it really fulfilled my desires. I was left with a feeling of satisfaction.

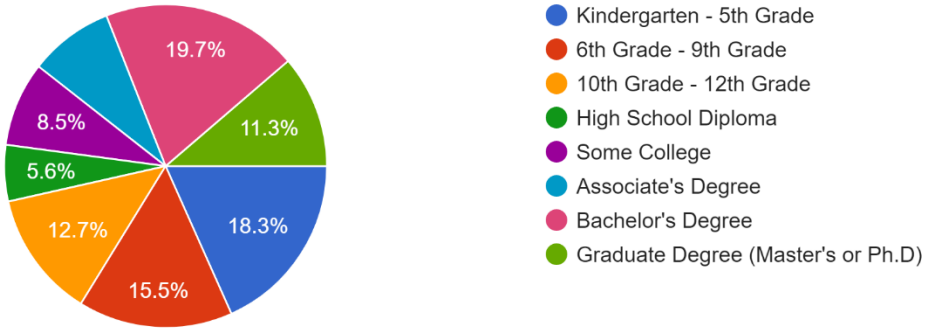
What is your age range, or the age range of the person you are taking this survey for?

71 responses



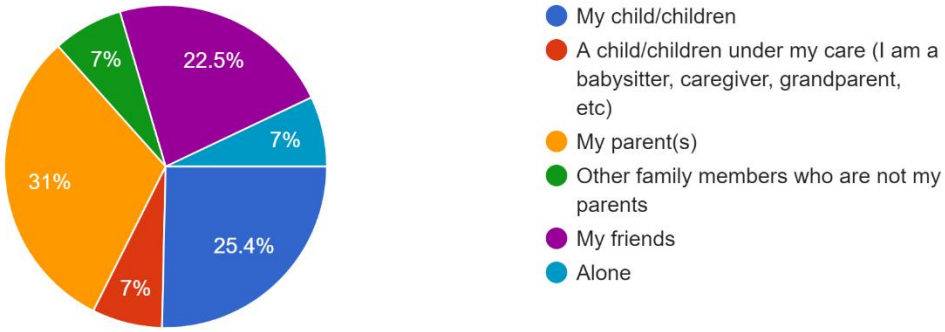
What is your highest level of education?

71 responses



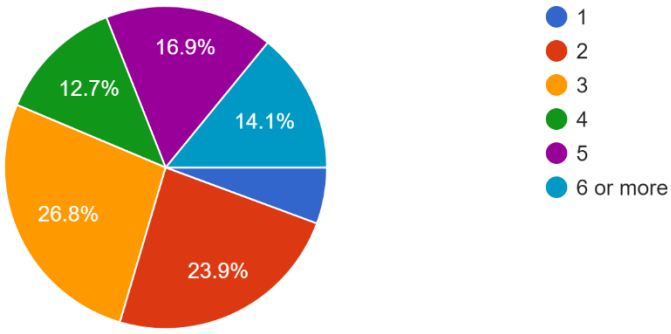
Who did you visit the museum with today?

71 responses



How many people did you visit with today (including yourself)?

71 responses



Bibliography

Bunce, Louise. "Dead Ringer? Visitors' Understanding of Taxidermy as Authentic and Educational Museum Exhibits." *Visitor Studies* 19, no. 2 (2016): 178–92. https://doi.org/10.1080/10645578.2016.1220189.

Candlin, Fiona. *Art, Museums and Touch*. Manchester: Manchester University Press, 2010.

Candlin, Fiona. "Rehabilitating Unauthorised Touch *or* Why Museum Visitors Touch the Exhibits." *The Senses and Society* 12, no. 3 (2017): 251–66. https://doi.org/10.1080/17458927.2017.1367485.

Candlin, Fiona. "The Dubious Inheritance of Touch: Art History and Museum Access." *Journal of Visual Culture* 5, no. 2 (2006): 137–54. https://doi.org/10.1177/1470412906066906.

Carr, Elizabeth. "Visitor Study: MUSE 360 Data," RIT Museum Studies Program, unpublished work, March 7, 2019.

Carr, Elizabeth. "Visitor Study: RMSC Data," RIT Museum Studies Program, unpublished work, February 23, 2019.

Comes, Randu, Zsolt Buna, and Ionut Badiu. "Creation and Preservation of Digital Cultural Heritage." *Journal of Ancient History and Archeology* 1, no. 2 (August 2014): 50–56.

Coulston, Jon. "The Study of Trajan's Column | Trajan's Column." Trajan's Column. Accessed October 14, 2018. https://arts.st-andrews.ac.uk/trajans-column/the-project/the-study-of-trajans-column/.

Curran, Katherine. "The Process of Creating Accurate Reproductions of Fragile Objects: Fabricating 3D Facsimiles with Limited Resources." Undergraduate Thesis, Rochester Institute of Technology, May 1, 2017. https://scholarworks.rit.edu/theses/9597.

Goldberg, Dana. “History of 3D Printing: It’s Older Than You Think [Updated].” *Redshift EN* (blog), April 13, 2018. https://www.autodesk.com/redshift/history-of-3d-printing/.

Hess, Mona, and Stuart Robson. “Re-Engineering Watt: A Case Study and Best Practice Recommendations for 3D Colour Laser Scans and 3D Printing in Museum Artefact Documentation.” Proceedings paper. Lasers in the Conservation of Artworks IX, 2013. http://www.lacona9.org/publication.php.

“Inuit Snow Goggles.” Vancouver Maritime Museum, March 14, 2007. https://web.archive.org/web/20070314111555/http://www.vancouvermaritimemuseum.com/modules/vmmuseum/treasures/?artifactid=77.

Klein, Susanne, Michael Avery, Guy Adams, Stephen Pollard, and Steven Simske. “From Scan to Print: 3D Printing as a Means for Replication,” Hewlett-Packard Development Company, 2014, 6. https://www.semanticscholar.org/paper/From-Scan-to-Print%3A-3D-Printing-as-a-Means-for-Klein-Avery/cb598dac18ffdb83252ad736dc632679054052ce#paper-header

Latham, Kiersten F. “Numinous Experiences With Museum Objects.” *Visitor Studies* 16, no. 1 (2013): 3–20. https://doi.org/10.1080/10645578.2013.767728.

Maerker, Anna. “Towards a Comparative History of Touch and Spaces of Display: The Body as Epistemic Object.” Edited by GESIS-Leibniz-Institut Für Sozialwissenschaften. *Historical Social Research / Historische Sozialforschung* 40, no. 1 (2015): Focus: 284-300. https://doi.org/10.12759/hsr.40.2015.1.284-300.

Neumüller, Moritz, Andreas Reichinger, Florian Rist, and Christian Kern. “3D Printing for Cultural Heritage: Preservation, Accessibility, Research and Education.” In *3D Research Challenges in Cultural Heritage: A Roadmap in Digital Heritage Preservation*, edited by

Marinos Ioannides and Ewald Quak, 119–34. Berlin: Springer Berlin Heidelberg, 2014. https://doi.org/10.1007/978-3-662-44630-0_9.

Pattison, Scott A., and Todd Shagott. "Participant Reactivity in Museum Research: The Effect of Cueing Visitors at an Interactive Exhibit." *Visitor Studies* 18, no. 2 (2015): 214–32. https://doi.org/10.1080/10645578.2015.1079103.

Rogers, Tony. "Everything You Need To Know About Polylactic Acid (PLA)." Accessed January 31, 2019. https://www.creativemechanisms.com/blog/learn-about-polylactic-acid-pla-prototypes.

Smithsonian Institution. "Snow Goggles." Alaska Native Collections. Accessed February 19, 2019. https://alaska.si.edu/record.asp?id=550.

Victoria and Albert Museum. "Trajan's Column - Victoria and Albert Museum." Last modified 2016. Accessed October 4, 2018. http://www.vam.ac.uk/content/articles/t/trajans-column/.

Zalewski, Daniel. "The Factory of Fakes." *New Yorker* November 28, 2016, 69-79. https://www.newyorker.com/magazine/2016/11/28/the-factory-of-fakes.